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In this manual, the theoretical concepts underlying each poultry waste management approact are discussed, and process design methodologies are presented. Included are design examples to illustrate the application of design methodologies. A discussion of the impact of design decisions on performance characteristics and computer programs to assist in the process design for each alternative are also presented.

Both high-rise, undercage drying and aeration systems are compared to identify relative merits and provide economic projections. Odor control and plant nutrient conservation capabilities as well as refeeding potential for both alternatives are discussed.

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A Design and Application Manual

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FOREWORD

Environmental protection efforts are increasingly directed towards preventing adverse health and ecological effects associated with specific compounds of natural or human origin. As part of this Laboratory's research on the occurrence, movement, transformation, impact, and control of environmental contaminants, the Technology Development and Applications Branch develops management or engineering tools for assessing and controlling adverse environmental effects of agricultural practices.

To meet the increasing food needs of the nation, the agricultural industry has adopted improved production practices and increased the size of individual farm facilities. Although clearly beneficial in increasing food production, these large facilities have produced waste management problems that threaten the environmental quality of the water and air. This report describes waste management techniques to provide control of odor problems and water pollution from egg production activities in a form that can be used by engineers, extension personnel, and egg producers.

David W. Duttweiler
Director
Environmental Research Laboratory
Athens, Georgia

ABSTRACT

Changes in the egg production industry during the past 20-30 years have produced waste management problems which threaten both water and air quality. Results from a number of research studies have identified two processes--aerobic, biological stabilization and drying--that provide both odor control and the reduction of the water pollution potential of these wastes.

In this manual, the theoretical concepts underlying each poultry waste management approach are discussed, and process design methodologies are presented. Included are design examples to illustrate the application of design methodologies. A discussion of the impact of design decisions on performance characteristics and computer programs to assist in the process design for each alternative are also presented.

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CHAPTER 1

INTRODUCTION

1.1 Background and Purpose

During the past 20-30 years, the agricultural segment of the nation's economy has undergone significant change. A shift toward a high degree of specialization and the concentration of production on fewer but larger farms has resulted. These changes have occurred in response to the increased demand for food due to the population expansion and to the need to maintain or improve profitability through increased efficiency. The development and availability of improved production practices have made these changes possible.

Nowhere have these changes been more dramatic than in the production of animal products. The egg production industry is a particularly noteworthy example. In this industry, there has been a steady decline in the number of commercial egg farms. However, the size of the remaining enterprises in terms of numbers of laying hens has increased. Data for the years 1964 and 1969 (Table 1.1) illustrate these trends. More recent preliminary census data (Table 1.2) indicate that these trends are continuing. Today (1977), the minimum size of an economically viable unit is about 30,000 birds if egg production is the only source of income. Larger operations are the rule rather than the exception with farms containing 500,000 to 1,000,000 laying hens not uncommon.

While these changes are clearly beneficial in terms of the availability and cost of food, they have produced waste management problems which threaten the quality of the environment. The trend toward fewer but larger poultry farms has produced larger quantities of these wastes at specific sites increasing the potential for pollution of surface and ground waters. In addition, the adoption of high density, confinement production techniques has resulted in wastes creating serious odor problems.

In the egg production industry, the trend toward intensification has been accompanied by specialization. In the past, many farms combined egg production with other enterprises such as grain production. Today many farms, especially the larger operations, purchase some or all of the required feedstuffs. Therefore land for crop production may not be part of the egg production enterprise and opportunities for waste disposal may be limited.

Clearly, a balance between food production and environmental quality is needed. A return to former production practices can not meet current demands for food and still maintain the present high standard of living. However, adoption of

TABLE 1.1. EGG PRODUCTION FLOCK NUMBER AND SIZE CHANGES, U.S. (1)

	1964			1969		
	Chickens on hand, 4 months old and over			Chickens on hand, 3 months old and over		
	Number of farms (1,000)	Percent of farms	Percent of birds	Number of farms (1,000)	Percent of farms	Percent of birds
Under 100	896.2	73.7	7.3	337.7	71.7	2.7
100 - 3,199	300.9	24.7	30.7	115.1	24.4	10.8
3,200 - 9,999	12.9	1.1	21.0	9.2	2.0	14.9
10,000 and over	5.8	0.5	41.0	8.9	1.9	71.6
	1,215.8	100.0	100.0	470.9	100.0	100.0

TABLE 1.2. CHANGES IN THE EGG PRODUCTION INDUSTRY BETWEEN 1969 AND 1974 (2)

	Farms With Sales Exceeding $2500	
	1974	1969
Number of Farms	196,764	280,007
Number of Birds*	277,003,509	290,900,729

*Hens and pullets of laying age, 3 months or older.

low standards of environmental quality also is unacceptable. The solution is the development of new animal waste management techniques which will protect the environment and simultaneously maintain or increase levels of both production and efficiency.

During the past several years, the development of new techniques for the management of the manure resulting from intensive egg production activities has been the objective of a number of research studies. The result has been the identification of two processes--aerobic, biological stabilization and drying--that provide both odor control and the reduction of the water pollution potential of these wastes. Both processes have been examined in laboratory, pilot plant, and full-scale studies. The results of these studies have identified feasible design and operating modes, as well as have provided a basis for estimation of capital and operating costs.

The objective of this manual is to assemble and translate this information into a form that can be used by engineers, extension personnel, and egg producers to:

1. Understand the relative merits of aeration and drying systems for the management of poultry wastes.

2. Design such systems to achieve a desired quality of liquid or dry end-product and to accomplish odor control, waste stabilization, and nitrogen control as necessary.

1.2 Scope of [illegible] Manual

The contents of this manual include:

1. A discussion of production rates and the physical and chemical characteristics of poultry manure including variability and its causes.

2. A discussion of the theoretical concepts involved in both the aerobic stabilization and drying approaches to poultry waste management.

3. Presentation of process and physical design information as well as design examples for each system.

4. A discussion of the relative merits of each system along with economic projections to provide a basis for system selection for specific situations.

1.3 Historical Background

Before proceeding, it appears useful to briefly examine the developments in the egg industry which have created the present problems of waste management. Perhaps the most important factor in the development of commercial egg production as it exists today was the change from the floor to the cage management system. As the name implies, the floor system consisted of hens unconstrained on the floor of pens. Sawdust, straw or some similar material was placed on the pen floor, and the accumulated manure mixed with this material. The result, termed litter, provided a medium for stabilization through drying and a degree of biological activity. It also provided a storage mechanism for periods of up to 12 months which represents a normal laying cycle.

The floor or litter system had two disadvantages which resulted in the conversion to the cage management system. One, the cage system allowed an increase in bird density which lowered housing costs per hen. The minimum floor area per bird in a floor system was about 0.19 square meters (2 square feet). At higher densities, the litter could not be kept dry and dirty eggs and disease problems resulted. Conversion to the cage system reduced floor area per bird to about 0.04 square meters (0.45 square feet).

The second disadvantage of the floor system was its high labor requirements. Although mechanical feeders were first used with floor systems, egg collection and manure handling remained manual tasks. With a floor system, one man could care for 5,000 to 10,000 birds. Today, with cages, one man can handle from 35,000 to 50,000 hens.

The adoption of new management techniques resulted in changes in both physical waste characteristics and the nature of poultry farms. With the increase in bird density, the natural drying and stabilization which was characteristic of the floor system no longer occurred. The raw waste, which has a moisture content of about 75 percent on an as excreted wet basis, was collected in pits constructed below the cages. In the "as produced" form, these wastes were difficult to handle since they were not amenable to either conventional liquid or solid handling techniques. Due to the semi-solid nature of the waste, the transition to liquid handling systems occurred. Additional water was normally added directly or via water spillage to create a pumpable slurry. Liquid manure systems were attractive because the physical labor associated with manure handling was reduced.

The shift to handling poultry manure in either a semi-solid or liquid form created an ideal environment for uncontrolled, anaerobic microbial activity. Such activity results in objectionable odors which are exhausted through ventilation fans and are dispersed when the wastes are disposed of on the land.

The odors consist of malodorous mercaptans, amines, volatile acids, and sulfides. In addition to malodors, these forms of poultry manure provided an attractive breeding site for vermin, particularly the common house fly, Musca domestica. These problems were intensified by suburban encroachment into agricultural areas. Odor problems related to poultry farms have resulted in legal or administrative actions by a number of state environmental agencies.

Concurrent with the shift to the cage system was the beginning of the trend toward fewer but larger poultry farms as discussed previously. As flock size increased, many farms reduced or eliminated cropping activities and purchased some or all the feed required. Therefore, land for the production of feed is not necessarily a requirement for egg production. In many instances the purchase of feed may present economic advantages. The combination of large populations and limited land resources can result in heavy waste loadings on small areas. This intensifies the potential for water pollution. A not untypical examples would be a 250,000 bird farm with only 16.2 hectares (40 acres) of land available for waste disposal.

1.4 Water Pollution Potential

Odor represents the most perceptible pollution problem associated with poultry manure. However, these wastes also possess a significant water pollution potential due to the presence of nutrients and oxygen demanding materials. Wastes that are discharged to surface waters require high levels of removal of both oxygen demanding and nutrient compounds. In contrast, the effluent guidelines for the feedlot industry (3) state that animal wastes should not be discharged to watercourses. This is in keeping with the historic practice of returning animal manures to the land. The use of the land for ultimate disposal is an important factor in identifying ultimate waste management objectives.

In light of the waste stabilization capacity of soils, emphasis in animal waste management should be directed towards preventing the movement of oxygen demanding and nutrient fractions into surface and ground waters. This can be achieved in some instances by management strategies limiting ultimate disposal to situations conducive to nutrient uptake by crops and least susceptible to surface runoff events. Where biological waste stabilization is desired, emphasis should be on the removal of the oxygen demanding and nutrient fractions which are susceptible to movement to surface and ground waters. This level of stabilization also can provide effective odor control.

Two important water pollution characteristics of poultry manure are the soluble organic fraction and the nitrogen content. The soluble carbonaceous fraction of poultry manure is significant. As much as 24 percent of the chemical oxygen demand (COD) can be soluble (4). Storage under uncontrolled anaerobic conditions will increase the soluble organic fraction.

Poultry excreta contains the highest concentration of nitrogen (Table 1.3) of the major agricultural species of domestic animals. Of particular concern is the loss of nitrogen to both surface and ground waters where land resources for waste disposal are limited. Numerous studies (8, 9, 10) have shown that nitrogen is the limiting parameter in the disposal of animal wastes to the land. Application rates should be limited to crop production requirements.

Thus, poultry waste management approaches should be geared to using such application rates. Where land area is limited, these approaches may need to include appropriate nitrogen control methods.

TABLE 1.3. TOTAL KJELDAHL NITROGN, PERCENTAGE OF TOTAL SOLIDS IN ANIMAL WASTES

	Beef	Dairy	Swine	Laying Hens
TKN, % of TS	1.9 (5)*	4.9 (6)	3.4 (7)	7.8 (4)

*Numbers in parentheses indicate data source.

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CHAPTER 2

RAW WASTE CHARACTERISTICS

2.1 Introduction

Knowledge of the physical and/or chemical characteristics of poultry manure is necessary for the design of both aerobic biological stabilization systems and drying systems. Information defining "typical" characteristics of the wastes from caged, White Leghorn laying hens is available from several sources (1, 2, 3, 4). These values (Table 2.1) represent averages of data presented by several investigators. For example, characteristics presented by the U.S. Environmental Protection Agency (USEPA) (1) and Jones, et al. (3) were originally reported by Miner (5) and were developed from data of Dornbush and Anderson (6), Hart and Turner (7), and Taiganides. Comparison of these values (Table 2.1) with other available data indicates that considerable variation exists. Therefore, the suitability of "typical" or average values that can be used for design purposes is questionable. Use of such values could result in either under or over-design with the possible result of excessive operating costs or process failure.

While on-site sampling is the best approach to determine waste characteristics, this practice may not be possible for the design of new facilities. Therefore an understanding of the causes of variation of waste characteristics and of a method to estimate actual waste characteristics is necessary for effective design of poultry waste management systems.

The objectives of this chapter are to present:

1. A review of reported poultry manure characteristics.
2. A discussion and analysis of the factors which may be responsible for the observed variations.
3. The development of an approach to estimate waste characteristics when sampling and analysis is not possible.

2.2 Reported Poultry Manure Characteristics

The characteristics of manure from various genetic strains of the White Leghorn hen have been reported by several investigators. A summary of reported values is presented in Table 2.2. The values presented are reported data only from studies where a 24 hour manure collection period was used with analysis immediately following the collection period. Only such data were included because the 24 hour collection period integrates possible variation in manure production rate throughout the day.

TABLE 2.1. "TYPICAL" CHARACTERISTICS OF MANURE FROM CAGED, WHITE LEGHORN LAYING HENS, GM/BIRD-DAY

Reference	Wet Solids	Moisture	TS*	VS*	TN*	COD*
(1)	120.5	102.3	35.5	26.4	23.5	32.1
(2)	108.3	81.0	27.4	19.2	1.5	24.5
(3)	120.5	102.3	35.5	26.4	4.1	32.1
(4)	127.4	95.6-101.4	25.5-31.8	-	0.5-2.0	-

*TS = Total Solids
VS = Volatile Solids
TN = Total Nitrogen
COD = Chemical Oxygen Demand

As shown in Table 2.2, significant differences exist for each parameter. Comparison of "typical" values for each parameter presented in Table 2.1 and the range of values in Table 2.2 shows that while the typical values generally fall within the range for each parameter, the range for each parameter is quite large. Therefore, neither the typical values nor data from any study reported in the literature can be used with confidence for design purposes. It should be noted that the value of total nitrogen (TN), 23 gm/bird-day, presented by USEPA (1) appears to be a mistake. Miner (5) reported TN production as 11.5 percent of total solids. USEPA (1) reported TN as 0.0115 kilograms per kilogram of liveweight per day or 66 percent of total solids.

2.3 Potential Factors Affecting Manure Characteristics

There are several factors which may be responsible for the variation in the characteristics of poultry manure. These include stage of the laying cycle, genetic strain, and characteristics of the diet. The following discusses these various factors.

The laying cycle can be divided into three phases (13). During Phase I, body weight increases from 1450 to 1900 grams and egg production increases from zero to 85 percent. Egg production declines to 65 percent during Phase II, and is less than 65 percent during Phase III. There is a relationship between the three phases of egg production, feed consumption, and manure production.

In a study of manure characteristics during the three phases of the laying cycle, Hashimoto (14) reported that variations in the ratios of wet solids, total solids, volatile solids, and total nitrogen production to total solids production were generally less than one standard deviation from the yearly

TABLE 2.2. CHARACTERISTICS OF MANURE FROM CAGED, WHITE LEGHORN LAYING HENS, GM/BIRD-DAY

Reference	Strain	Wet Solids	Moisture	TS*	VS*	TN*	COD*	Date of Study
(6)	Honegger	106.1	77.3	28.8	20.2	1.4	23.0	1964
(7)	-	63.7	33.7	30.0	23.2	1.6	25.8	1965
(8)	Shaver	108.4	78.8	29.6	22.1	2.3	19.2	1973-74
		96.7	67.7	29.0	20.6	2.2	21.4	1974-75
(9)	Hyline	145.4	110.4	35.0	25.6	2.4	-	1974
	Babcock	140.4	103.5	36.9	27.1	2.4	-	
	H & N**	145.4	109.5	35.9	26.9	2.5	-	
	Hubbards	148.3	111.8	36.5	26.8	2.5	-	
(10)	Babcock	-	-	37.2	27.6	3.1	28.9	1972-73
(11)	H & N**	127.1	98.6	28.5	21.1	1.8	18.9	1969-71
(12)	Babcock	189.7	141.5	48.2	32.6	2.8	36.4	1970
- Range of values		63.7-189.7	33.7-141.5	28.5-48.2	20.2-32.6	1.4-3.1	18.9-36.4	

* TS = Total Solids
VS = Volatile Solids
TN = Total Nitrogen
COD = Chemical Oxygen Demand
** Heistoff and Nelson

average. Yearly averages and standard deviations for three flocks of birds studied by Hashimoto are presented in Table 2.3. In light of the data presented by Hashimoto (14), it appears that possible differences in the stage of laying cycle are not responsible for the wide variation in reported waste characteristics (Table 2.2). Moreover, it appears that yearly averages are acceptable for design purposes.

TABLE 2.3. CHARACTERISTICS OF WHITE LEGHORN, LAYING HEN MANURE (14)

	Production (gm/bird-day) ± 1 Standard Deviation		
	Flock 1 n = 80	Flock 2 n = 52	Flock 3 n = 9
Wet Solids	99 ± 23	99 ± 17	111 ± 5
Moisture	73 ± 23	74 ± 17	87 ± 5
Total Solids	26 ± 4	25 ± 5	24 ± 2
	Percent of Total Solids ± 1 Standard Deviation		
Total Nitrogen	8 ± 2	8 ± 1	8 ± 1
Chemical Oxygen Demand	56 ± 29	62 ± 15	58 ± 4

Little is known concerning the relationship between genetic strain and manure characteristics. However, data (9) from a study involving four different strains of White Leghorn hens housed in the same environment and receiving the same diet indicated no significant difference in waste characteristics as related to genetic strain (Table 2.2). However, the results of three separate studies (9, 10, 12) involving the Babcock strain show considerable variation. Therefore, while it appears that genetic strain is not a significant factor concerning the characteristics of wastes from White Leghorn hens, this conclusion may apply only to the different genetic strains of the White Leghorn breed. It may not be applicable when considering other breeds such as the Rhode Island Red.

Consideration of the third factor, diet, requires an understanding of some of the basic concepts of poultry nutrition. Although taste has a large influence on the amount of food consumed by man and certain other mammals, it appears to be of minor importance in feed consumption by poultry (13). The energy requirement seems to be the primary factor governing feed consumption by the chicken. The laying hen can adjust her feed consumption of diets containing from 2500 to 3300 kilocalories of metabolizable energy (ME) per kilogram of feed (1135 - 1500 kcal per lb) to obtain adequate energy. The hen will increase feed consumption until adequate metabolizable energy is obtained. With feeds containing low levels of ME, a greater quantity of feed will be consumed as compared to feeds with greater ME content. Therefore, feed consumption will increase as the metabolizable energy of the diet decreases and an increase in the quantity of total solids (TS) excreted should occur. Energy requirements for the laying hen are not constant. They vary slightly with the phase of the laying cycle and more significantly with climate. The daily energy requirement for the White Leghorn hen varies from 310 kcal ME/day in cooler climates to 265 kcal ME/day in warmer regions (13). However, lower energy feeds are commonly used in warmer regions somewhat offsetting lower feed consumption due to lower ME requirements.

Although the laying hen has specific protein requirements to maintain optimum productivity, intake of protein is governed by the relationship between protein and metabolizable energy in the diet. Daily dietary protein requirements for the three phases of egg production are 18, 16, and 15 grams of protein/hen-day (13). Since feed consumption is increased when ME is decreased and vice-versa, it is necessary to adjust the protein content of the diet to establish proper protein intake. This relationship is known as the ratio of metabolizable energy to protein percentage (ME/P) which has units kcal/kg/%. It is determined by dividing the kcal ME/kg of feed by the percentage of dietary protein. Values of ME/P to provide minimum protein requirements in cool climates are 166-170, 193-195, and 196-200 respectively for the three phases of egg production (13). For warm climates, a 10 percent reduction is suggested. As the ME/P ratio decreases from the minimum requirements thereby increasing protein intake, increase in the quantity of nitrogenous compounds excreted should occur.

Water consumption, like nitrogen intake, is principally a function of feed intake within the environmental temperature range of 14°C to 26°C (58-78°F) (13). With a diet containing approximately 10 percent moisture, water consumption under normal conditions may range from 1.5 to 2.0 grams of water/gram of feed consumed. Medway and Kare (15) found that water lost via respiration amounted to 53 grams/day for hens at 32 weeks of age. Water required/egg produced was reported to be approximately 35 grams. This suggests that the metabolic water requirements are relatively constant and increased water consumption due to increased feed intake should increase the quantity of moisture excreted.

To date (1977), only limited discussion of the relationship of feed to poultry waste characteristics has been published. In a study examining the practice of refeeding dehydrated poultry manure, Nesheim (16) observed an inverse relationship between fecal dry matter (total solids) as a percentage of feed consumed and as the quantity/hen-day and the metabolizable energy level of the diet. Data presented by Hashimoto (14) also showed the same inverse relationship between total solids excreted and metabolizable energy content of the feed. Of the several possible reasons for the observed variations in the characteristics of poultry wastes, the effect of differences in diet appears to be the most logical and fundamental. The observed relationships between the total solids excreted and the metabolizable energy content of the diet is discussed in detail in the following section.

2.4 Relationships Between Feed and Waste Characteristics

Based upon the above nutritional concepts, it was hypothesized that definitive relationships exist between feed and manure characteristics. Since information concerning feed characteristics in conjunction with waste characteristics is limited, it was only possible to examine three specific relationships. They are total solids production as a function of diet ME content, total nitrogen excreted versus the ME/P ratio, and the relationship between the quantity of moisture and total solids excreted. The last item represents an indirect method to examine the relationship between feed consumption and water excretion. This approach was necessary due to the lack of appropriate data.

To test the hypothesis that manurial total solids production is a function of the ME content of the feed, data presented by Hashimoto (14) and Nesheim (16) as well as other unpublished data (9, 17) were analyzed and are presented in Figure 2.1. Linear regression analysis using the least squares method was used to fit a straight line to the data. The regression coefficient of 0.97 indicates that a linear relationship exists between the two variables over the range of values analyzed. The mathematical relationship was:

$$\text{Total solids excreted, gm/bird-day} = -.038\,(\text{feed ME content, kcal/kg}) + 138 \qquad (2.1)$$

for feed ME values between 2445 and 3018 kcal per kg. This relationship suggests that not only can manurial total solids production be calculated from feed ME content, but also that use of higher energy feeds will reduce manurial total solids production.

The second relationship examined was that between the ME/P ratio of the feed and the quantity of nitrogen excreted/day. The available data (8, 9, 18) are presented in Figure 2.2. Again, linear regression analysis was used to fit a straight line to the data and to determine the mathematical relationship between the data. This relationship was:

$$\text{Total nitrogen excreted, gm/bird-day} = -.018\,(\text{ME/P ratio of the feed}) + 5.09 \qquad (2.2)$$

for ME/P ratios between 151.5 and 177.5. This relationship shows that as protein intake increases within the range of values analyzed, the quantity of nitrogen excreted will also increase.

The third relationship analyzed was that between the quantity of moisture and total solids excreted/bird-day. The data presented in Table 2.2 was used as the basis for this analysis. As noted, this approach represents an indirect method of examining the relationship between the consumption of water in relation to feed intake and moisture excreted. The data used and the results of the linear regression analysis are presented in Figure 2.3. The mathematical relationship between the two variables is:

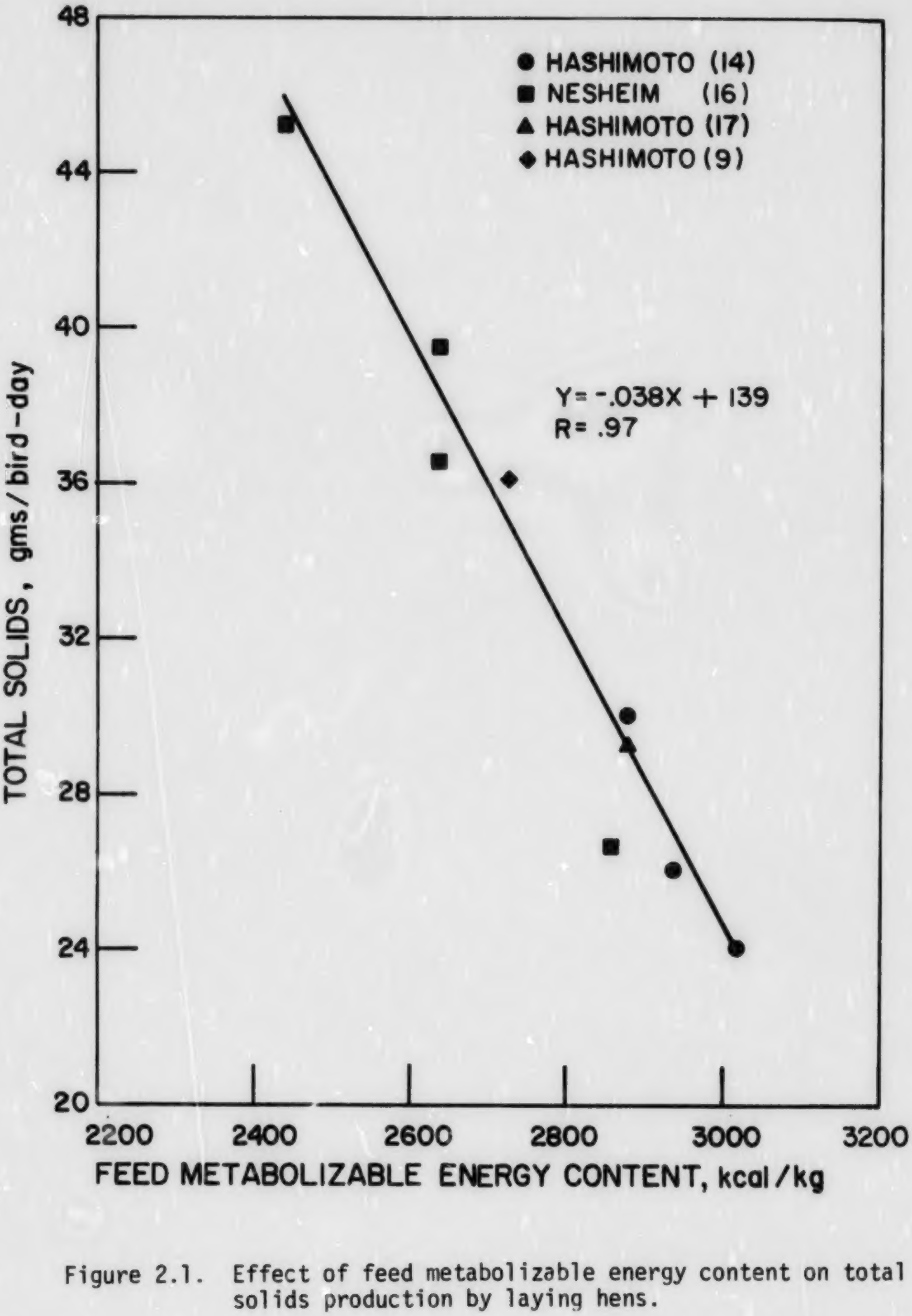

Figure 2.1. Effect of feed metabolizable energy content on total solids production by laying hens.

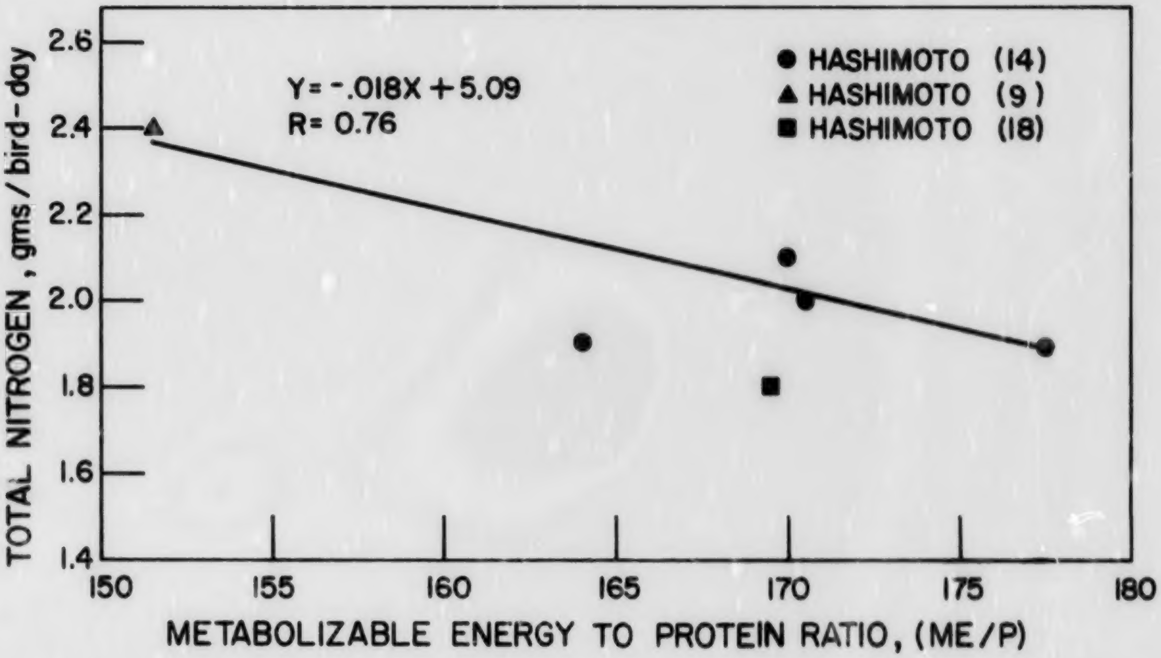

Figure 2.2. Effect of metabolizable energy to protein ratio on the quantity of total nitrogen excreted by laying hens.

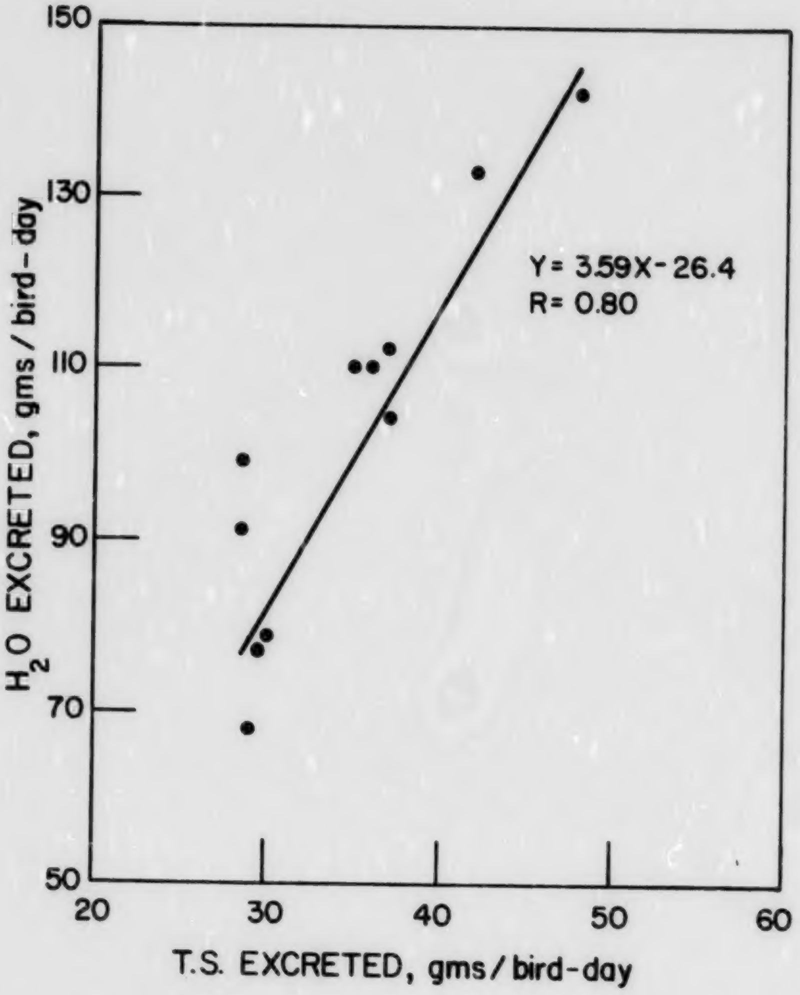

Figure 2.3. Relationship between excretion of total solids and moisture by laying hens.

$$\text{gm } H_2O \text{ excreted/bird-day} = 3.59 \text{ (gm total solids excreted/bird-day)} - 26.4 \qquad (2.3)$$

for total solids values between 28.2 and 48.2 gm /bird-day. This relationship indicates that when lower feed ME content results in increased feed consumption, the quantity of moisture as well as total solids excreted increases.

While it is clear that feed characteristics should also effect other parameters such as volatile solids (VS), fixed solids (FS), and chemical oxygen demand (COD), sufficient information was not available to develop similar relationships for these parameters. In order to provide some basis to estimate values for these parameters for design, data presented in Table 2.2 was used to establish ranges of expected values. These values (Table 2.4) are presented as a percentage of total solids to enable use with the foregoing information.

TABLE 2.4. POULTRY WASTE CHARACTERISTICS

Parameter		Percent of Total Solids
Volatile Solids	-	67-77%
Fixed Solids	-	23-33%
Chemical Oxygen Demand	-	65-86%

2.5 Design Example

This example of the use of the above information determines the waste quantities that can be used for the design of a 30,000 bird waste management system. The birds will be White Leghorn hens. The feed for the hens is assumed to be a 16 percent protein laying ration containing 2800 kcal of metabolizable energy (ME) per kg of feed. The procedures to determine the quantities of total solids, total nitrogen, and water excreted per bird-day and for the specified number of birds are as follows:

A. Total solids - Using Equation 2.1, the quantity of total solids excreted/bird-day is:

$$-.038 \text{ (2800 kcal/kg of feed)} + 139 = 32.6 \text{ gm total solids/bird-day}$$

or 978 kg/day for 30,000 birds.

B. Total nitrogen - The metabolizable energy to protein ratio (ME/P) for the feed is:

$$\frac{ME}{P} = \frac{2800\ \text{kcal/kg}}{16\%} = 175$$

Using Equation 2.2, the quantity of nitrogen excreted/bird-day is:

$$-.018\ (175,\ \text{ME/P ratio}) + 5.09 = 1.94\ \text{gm total nitrogen/bird-day}$$

or 58.2 kg/day for 30,000 birds.

C. Moisture - From A, total solids production was calculated to be 32.6 gm/bird-day. Using Equation 2.3, the quantity of moisture excreted/bird-day is:

$$3.59\ (32.6\ \text{mg total solids excreted/bird-day}) - 26.4 = 90.6\ \text{gm}\ H_2O\text{/bird-day}$$

or 2718 kg/day for 30,000 birds.

Values/bird-day for these three parameters also may be determined directly from Figures 2.1, 2.2, and 2.3. When necessary, values for volatile solids (VS), fixed solids (FS), and chemical oxygen demand (COD) can be estimated from calculated values for total solids and percentages presented in Table 2.4. It is recommended that conservative values of 77 and 86 percent for volatile solids and COD be used. The values for VS, FS, and COD can be determined as follows:

D. Volatile solids - From A, total solids production was calculated to be 32.6 gm/bird-day. Using the value of 77 percent, the quantity of volatile solids excreted/bird-day is:

$$32.6\ \text{gm total solids/bird-day} \times .77 = 25.1\ \text{gm volatile solids/bird-day}$$

or 753 kg/day for 30,000 birds.

E. Chemical oxygen demand (COD) - Using the values of 32.6 gm of total solids/bird-day and 86 percent for COD, the quantity of COD excreted/bird-day is:

$$32.6\ \text{gm total solids/bird-day} \times .86 = 28.0\ \text{gm COD/bird-day}$$

or 841 kg/day for 30,000 birds.

F. Fixed solids - Using the previously determined values for total solids and volatile solids, the quantity of fixed solids excreted/bird-day is:

32.6 gm total solids/bird-day - 25.1 gm
volatile solids/bird-day =
7.4 gm fixed solids/bird-day

The poultry manure characteristics estimated in the preceding design example are summarized in Table 2.5.

TABLE 2.5. POULTRY MANURE CHARACTERISTICS ESTIMATED IN THE PRECEDING DESIGN EXAMPLE

Parameter	gm /bird-day	For 30,000 birds kg/day
Total Solids	32.0	978
Total Nitrogen	1.94	58.2
Moisture	90.6	2718
Volatile Solids	25.1	753
Chemical Oxygen Demand	28.0	841
Fixed Solids	7.4	222

Thus, it is possible to estimate the manure characteristics and quantities using the relationships identified in this chapter. This information is valuable in considering manure management alternatives and will be used in the manure management design examples presented in later chapters.

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CHAPTER 3

HIGH-RISE, UNDERCAGE DRYING OF POULTRY MANURE

3.1 Introduction

Research (1, 2, 3) has shown that the drying of poultry manure can be an effective waste management technique. The removal of water from such manure provides the following advantages:

A. Improvement in handling characteristics;

B. Reduction in weight and volume;

C. Reduction in offensive odor.

With the removal of moisture, poultry manure loses its adhesive qualities becoming granular in nature. In this state, it can be handled as a solid using equipment such as elevators, augers, and front-end loaders. The relationship between moisture content and handling characteristics for poultry manure is presented in Figure 3.1. In addition to the reduction in weight, a decrease in volume also occurs. Reduction in moisture content to equilibrium levels results in a volume reduction of 40 to 50 percent (5). One of the important benefits of drying is the odor control which results from moisture removal (Figure 3.2).

Although drying and biological treatment processes have the common objective of odor control, they differ in other areas. While biological treatment uses microbial activity to achieve waste stabilization through the conversion of carbonaceous compounds to carbon dioxide and water, the removal of water limits microbial activity in drying systems. This is consistent with the objective of odor control by minimizing the production of odorous compounds characteristic of uncontrolled anaerobic processes. Some waste stabilization can occur by microbial and/or physical mechanisms during the drying process.

While it can not be documented that drying poultry manure reduces the water pollution potential of these wastes via stabilization, it can be considered a management approach for water pollution control. Effective poultry manure drying permits the long term storage of these wastes without odor problems during storage or upon ultimate disposal to the land. This provides management flexibility to permit scheduling of ultimate disposal in a manner that will limit uncontrolled losses of contaminants to the environment.

Numerous approaches to the problem of removing moisture from poultry wastes have been investigated. Included are physical/chemical and evaporative

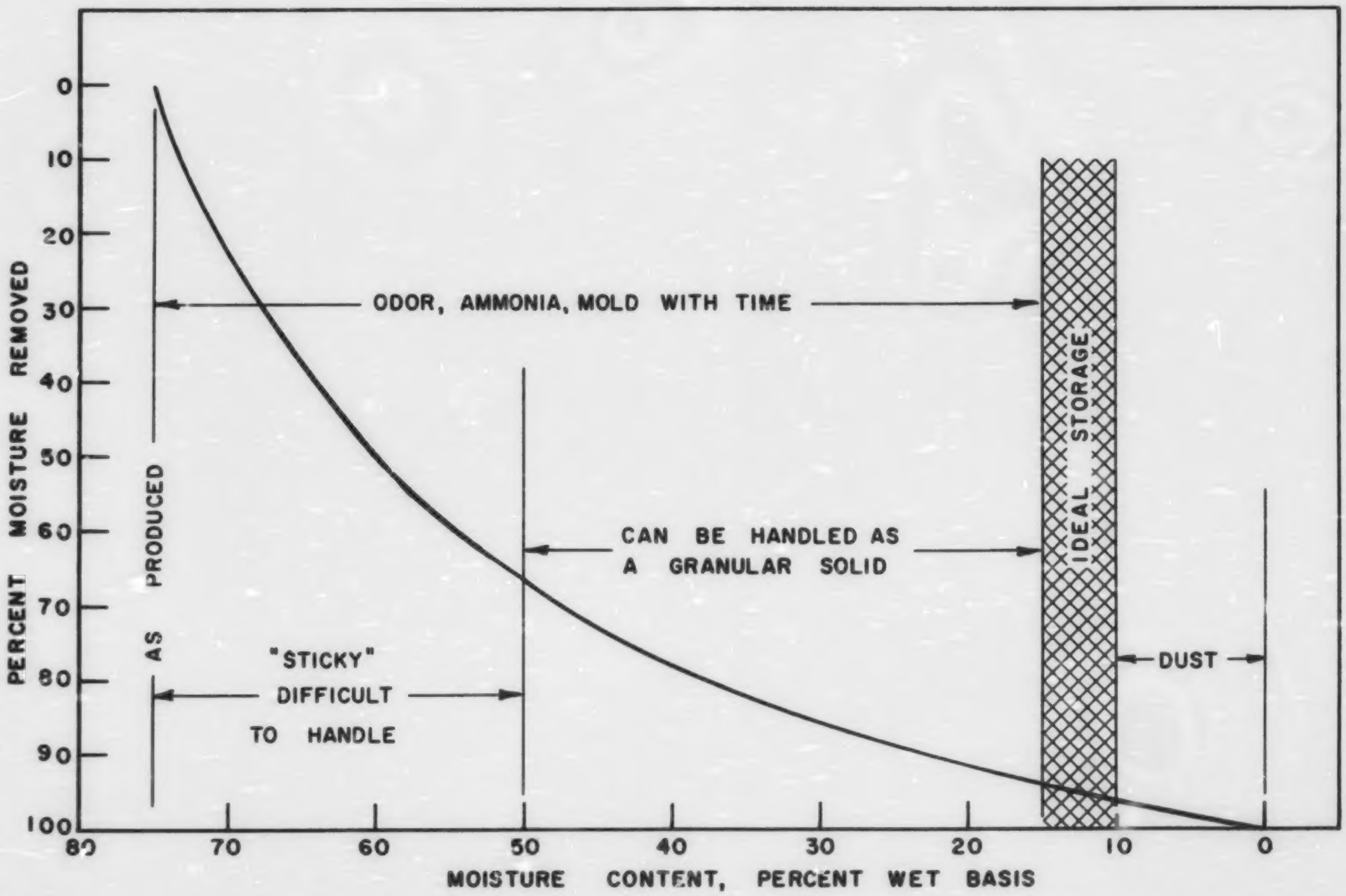

Figure 3.1. Characteristics of chicken manure related to moisture content (4).

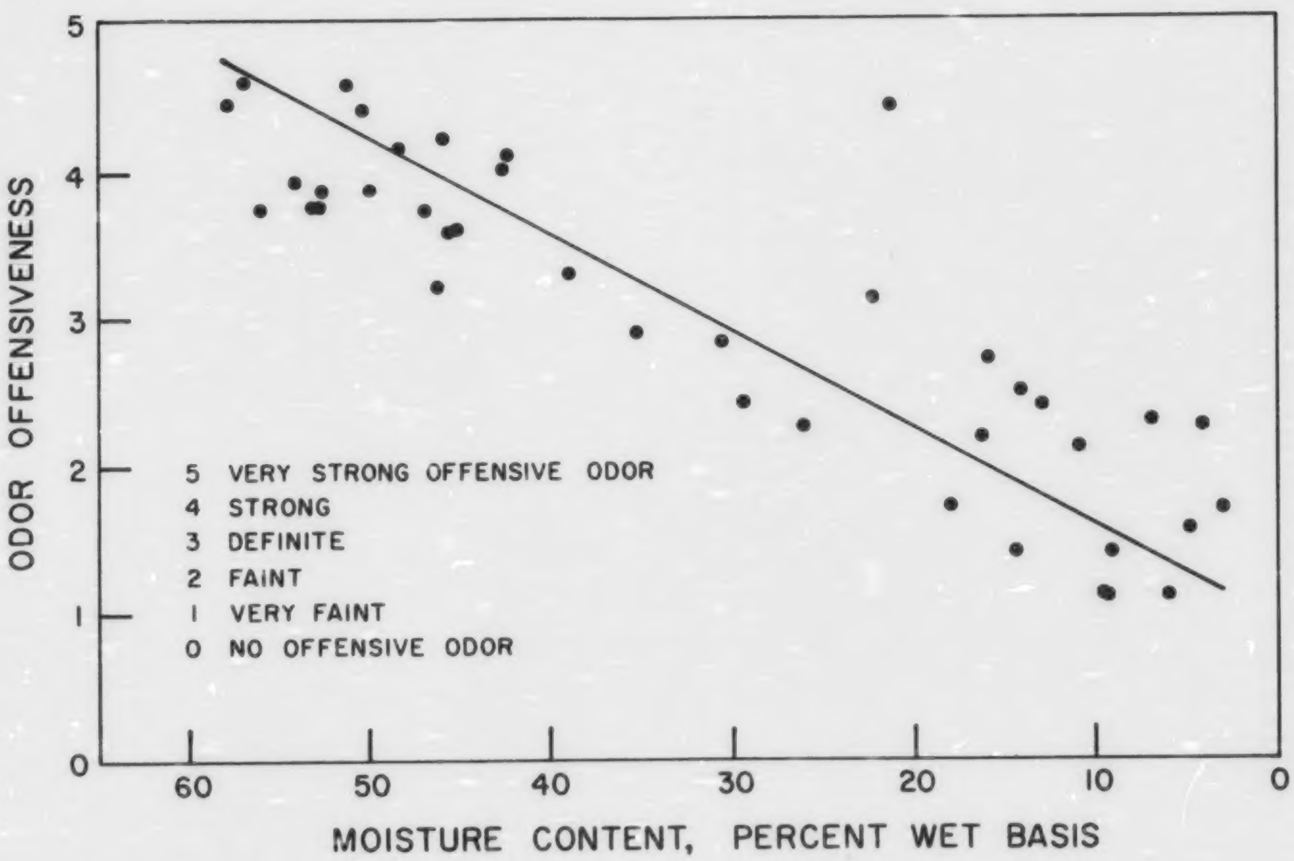

Figure 3.2. Odor offensiveness as a function of moisture content (5).

techniques. A study by Cassell (6) examined the use of a vacuum filter, a centrifuge and a hydraulic press for the dewatering of raw poultry wastes. Both the vacuum filter and the centrifuge required chemical conditioning and produced a cake with a total solids content of 20 to 25 percent. The most promising approach was the hydraulic press which produced a cake with a total solids content of 45 to 55 percent without chemical conditioning. However, all three approaches produced liquid effluent having a high in chemical oxygen demand (COD). Subsequent adoption of these techniques by the poultry industry did not occur.

Drying systems for poultry manure using both heated and unheated air have been developed and evaluated. Commonly, the input of heat energy is associated with industrial type manure driers such as rotary drum units. Unheated air normally is used with undercage drying systems.

The use of industrial type driers for the removal of moisture from poultry manure has been examined by several investigators. Ludington (7) presented a cost analysis of dehydration, pelleting, and bagging of poultry manure using a rotary drum drier. For a plant operating 24 hours per day and an initial manure moisture content of 76 percent, the processing cost was $34 per ton of dried manure. The cost for dehydration alone was $25.50 per ton. At a selling price of $20 per ton of pelleted manure, the cost of manure dehydration was estimated to be $0.17 per bird per year. These calculations were based on 1963 prices for energy and equipment. The present (1976) selling price of dried manure would have to be significantly higher to recover a comparable fraction of operating costs due to the increased energy and equipment costs.

Surbrook, et al. (2) presented a more favorable economic analysis of dehydration using a drier developed at Michigan State University. They estimated total costs to be $31.44 per dry ton in 1971. Assuming increases only in energy costs to $0.12 per liter ($0.45 per gallon) for No. 2 fuel oil and $0.035 per kilowatt-hour for electricity, present costs are estimated to be $49.98 per dry ton. It should be noted that neither figure includes equipment or energy costs for air pollution control devices.

The results of a study of the economic and technical feasibility of various types of industrial driers have been presented by Akers, et al. (8). They concluded that rotary drum driers are acceptable for poultry manure drying from a technical viewpoint. For small operations, agitated pan driers were found to be the most advantageous from both economic and technical aspects. For operations with an excess of one million birds, pneumatic driers had the lowest direct costs.

While the use of industrial type driers should not be discounted as a potential poultry waste management technique, their feasibility is clearly dependent on marketing of the finished product as a fertilizer or soil conditioner or a feed ingredient. The ability to realize this potential appears to be limited. In that design information concerning machine drying is available from various manufacturers, further discussion of this topic does not appear to be warranted.

Several approaches to in-house drying of poultry manure have been developed. Bressler and Bergman (1) utilized a high velocity, 2.5 m/sec (500 ft/min), unheated air stream above the manure surface. A stirring device similar to a spike tooth harrow was used for mixing to expose new surfaces to the airstream. This was a continuous flow system with no storage capacity. Moisture content of manure from this system ranged between 26.1 and 50.5 percent, wet basis, with the lowest moisture contents occurring during the summer months.

Sobel (9) achieved moisture contents of 29 to 35 percent, wet basis, using a forced air, undercage drying system. This system differed from the previous approach in that an air duct with a slot outlet was used to direct a uniform airstream over the poultry manure surface. A 7.6 cm (3 in.) accumulation of manure was maintained under the birds. This prevented sticking of manure to the dropping boards and provided a retention time of 5 to 8 days. The shallow bed of manure was mixed several times per day exposing new surfaces to the airstream.

One of the drawbacks of undercage, continuous flow drying concerns storage. Sobel and Ludington (10) have reported that the moisture content of dried manure should not be greater than 30 percent, wet basis, for successful storage. At higher moisture contents, malodors develop and the material regains its sticky and adhesive characteristics. While moisture reduction to 30 percent can be achieved with undercage drying, consistent performance at this level has not been possible. Therefore, supplemental treatment either in the form of composting or heated air drying appears necessary to permit storage.

Perhaps the most viable alternative for the drying of poultry manure is undercage drying in combination with a high-rise type house. In addition to the advantages of drying delineated earlier, this approach also provides acceptable storage for one or more years without supplemental treatment or handling.

3.2 Objectives

The objectives of this chapter are to:

A. Present a discussion of the development and a description of high-rise, undercage drying of poultry manure;

B. Discuss the theoretical concepts germane to the drying process;

C. Describe the experimental basis for and present the development of a rational process design approach for high-rise, undercage drying;

D. Outline process design methodology;

E. Discuss physical design considerations.

3.3 The High-Rise, Undercage Drying System for Poultry Manure

The development of the high-rise, undercage drying system for poultry manure can be traced to the use of deep pits under caged hens to provide long term manure storage. Early cage systems utilized shallow manure collection pits which required frequent cleaning. The deep pit house which provided long term manure storage was a further development. With this system, a 1.5 m to 2.4 m (5 ft to 8 ft) deep manure collection and storage area was located beneath the cages and normally below grade, hence the name deep pit.

Continuing development led to the original high-rise poultry house design. This differed from the deep pit only in that the bottom of the manure storage was located at or slightly above grade. This resulted in a two story building with the cages located on what would be the second floor. This change was made to eliminate the problem of water infiltration. Neither the shallow pit, the deep pit, nor the original high-rise house contained any provision for manure drying.

The high-rise undercage manure drying system, which will be the subject of discussion in this chapter, refers to the use of unheated, ventiliation air for manure drying within a high-rise poultry house. Therefore, the design of the ventilation system is a key factor in the manure drying process. Figures 3.3, 3.4 and 3.5 are cross-section, plan, and isometric views respectively of a typical poultry house employing the high-rise system of manure management. Banks of the exhaust ventilation fans are located in the manure storage area. Ventilation air enters the building through a slot inlet located at the eave level of the building. The air then passes through the cages, passes over the manure, and is finally exhausted to the atmosphere. As shown in Figures 3.3 and 3.4, circulating fans are located in the manure storage area to provide more uniform air circulation over the manure surface. This design differs from the early high-rise houses in the location of all ventilation fans and the use of circulation fans in the manure storage area.

With either flat deck or full stair-step cage systems, manure accumulates in a series of ridges and valleys conforming to the cage layout when drying occurs. These ridges are formed under the center of the cages with valleys under feed and water troughs and where cages are joined (Figure 3.6). With the triple deck cage system, ridge formation is less pronounced. The ridges are important since the surface area of the accumulated manure is increased, thus enhancing drying.

3.4 Theoretical Considerations

The removal of moisture from poultry manure can be accomplished by either mechanical or evaporative processes. However, evaporation is the process of interest in this discussion of undercage poultry manure drying in a high-rise poultry house. The objective of this section is to discuss the principles of evaporative drying and provide the theoretical basis for the system design relationships which will be presented subsequently.

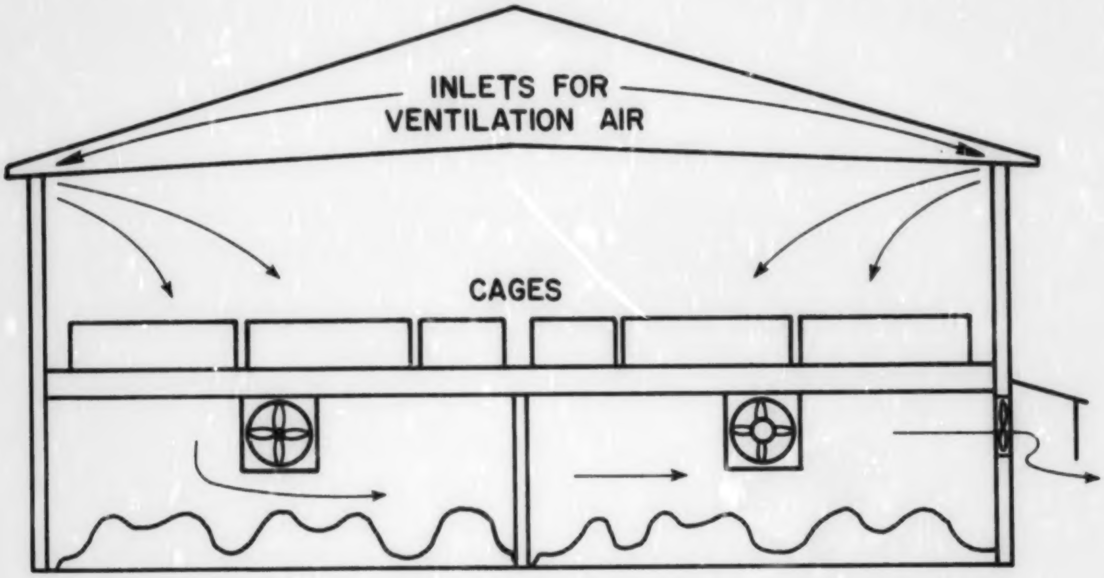
INLETS FOR
VENTILATION AIR
CAGES

Figure 3.3. Cross-section of a typical high-rise poultry house with undercage manure drying.

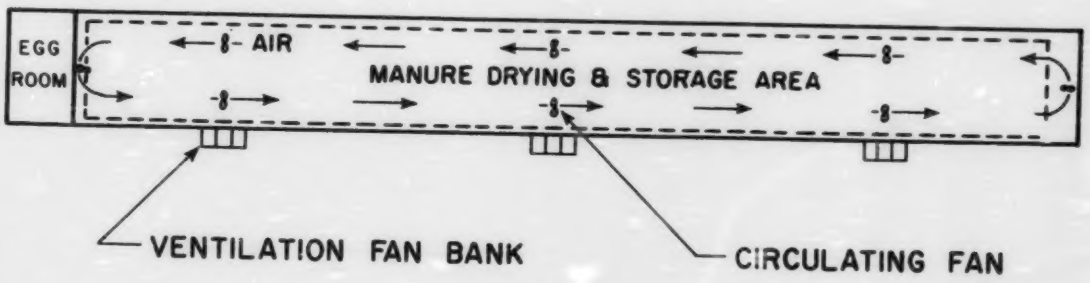
EGG ROOM
AIR
MANURE DRYING & STORAGE AREA
VENTILATION FAN BANK
CIRCULATING FAN

Figure 3.4. Plan view of a typical high-rise, undercage manure drying system showing location of drying air circulating fans.

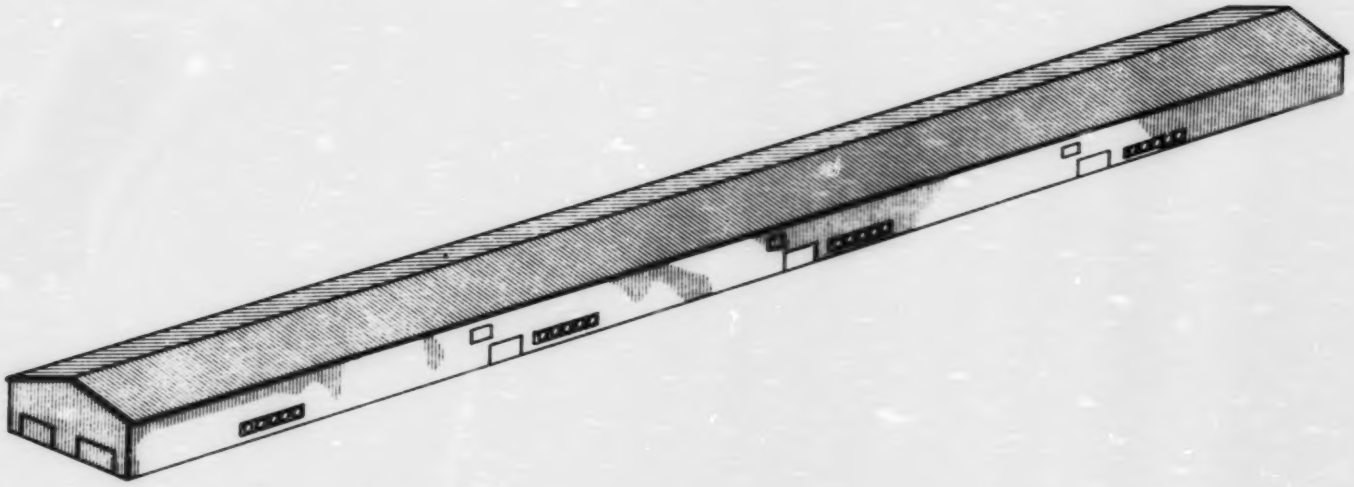

Figure 3.5. Isometric view of a high-rise poultry house.

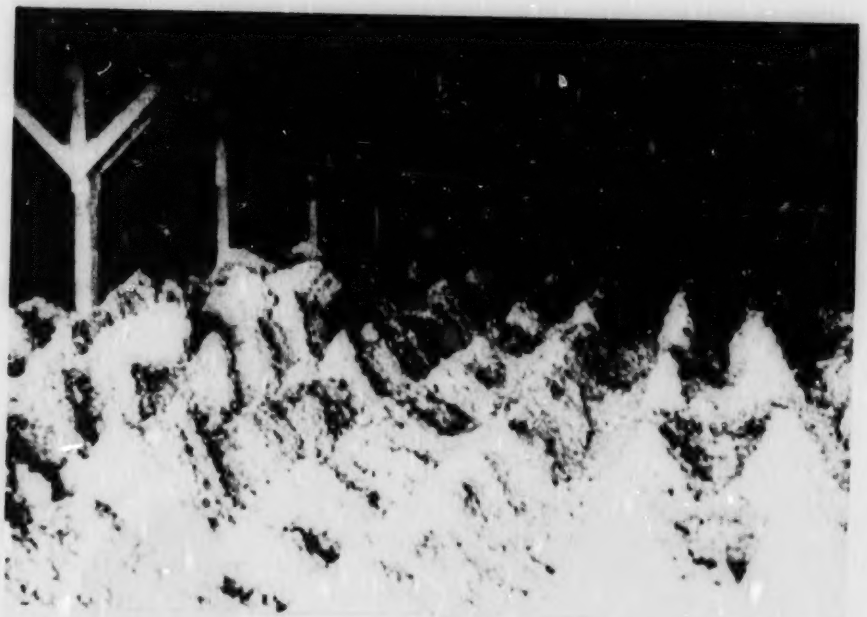

Figure 3.6. Ridge and valley formation in a high-rise, undercage manure drying system.

Evaporation is a characteristic of all liquids. It is the change in state from the liquid to the gas phase. While the terms drying and dehydration are normally used in conjunction with the removal of moisture from organic materials such as sewage sludges, various agricultural products, and animal manures, the reduction in moisture content is due to the evaporative process. Thus, the terms drying or dehydration merely represent specific cases of the evaporative process.

The terms drying and dehydration commonly are used interchangeably. However, their precise meanings differ Drying applies to any reduction in moisture content down to but not exceeding the equilibrium moisture content of the material in question. Dehydration is the reduction in moisture content to levels below the equilibrium moisture content.

Evaporation can be best understood by considering the physical structure of water. Any quantity of water is made up of a large number of molecules, each of which are in constant motion. As the result of kinetic energy exchanges between colliding molecules, some molecules acquire sufficient energy to overcome attractive forces and escape into the air as water vapor. Although molecules are continuously escaping the water surface, others are returning. The rate of evaporation is determined by the difference in the two rates. Condensation occurs when more molecules return to the body of water than escape.

Immediately adjacent to a water surface is a thin layer of air which is in thermal equilibrium with the water. This film is saturated with water vapor. If the air above this film has a lower moisture content, water vapor will be dispersed away from the liquid surface and evaporation will continue. The rate of evaporation is dependent on the difference in moisture content between the saturated film and that of the surrounding air.

The moisture content of air can be expressed in several ways. They include vapor pressure, absolute humidity, and relative humidity. However, both absolute and relative humidities are calculated from vapor pressure. The behavior of water vapor in air closely follows the general gas laws including Dalton's law of partial pressures. This law states that the pressure exerted by a mixture of gases is equal to the sum of the pressures that each gas would exert separately. The pressure that each individual gas, i.e., water vapor, exerts separately is termed the partial pressure of that gas. The partial pressure of water vapor in saturated air is called the saturation vapor pressure. The saturation vapor pressure and thus the moisture holding capacity of air is a function of temperature. Although saturation vapor pressures can be calculated using gas laws, experimentally determined values such as those presented in steam tables are considered to be more accurate (11).

The rate of evaporation is dependent on the difference between the vapor pressure of the saturated air film immediately adjacent to the water surface and the vapor pressure of the surrounding air. This principle, Dalton's Law (12), is expressed by:

$$E = C(P_s - P_a) \tag{3.1}$$

where: E = rate of evaporation, in./day

C = a coefficient dependent on barometric pressure, wind velocity and possibly other variables, day^{-1}

P_s = the vapor pressure in the air film next to a water surface which is the saturation vapor pressure corresponding to the temperature of the water, in. Hg

P_a = the vapor pressure of the surrounding air, in. Hg

Dalton's Law was expanded by Rohwer (13) to precisely define the effects of barometric pressure and wind velocity to predict evaporation from lakes and reservoirs. The Rohwer equation is:

$$E = 0.771\,(1.465 - 0.0186B)(0.44 + 0.118W)(P_s - P_a) \qquad (3.2)$$

where: B = barometric pressure, in. Hg

W = wind velocity, miles per hr

and E, P_s and P_a as previously defined.

Although research (5) has shown that the moisture loss from a manure surface is less than that from a water surface, the Rowher equation is useful in illustrating the principles of evaporative drying. As shown in Equation 3.2, evaporation will occur even under conditions of no air movement providing a vapor pressure differential exists. Air movement enhances evaporation due to the renewal of air in contact with the saturated air film.

The evaporative removal of moisture from many materials including poultry manure involves two processes. They are the movement of moisture from within the material to the surface and the evaporation of water from the surface. Based on the predominance of either factor, the drying process can be divided into two phases, the constant and falling rate periods. During the constant rate period, the material contains so much water that liquid surfaces exist. Under this condition, moisture will evaporate in a manner comparable to that from a free water surface. The rate limiting step in the constant rate phase is the mass transfer of water vapor from the saturated film to the vapor phase. Conversely, the falling rate period is characterized by the absence of liquid surfaces. In this period, the movement of moisture to the surface of the material is the rate limiting step.

In a study of the drying characteristics of poultry manure (5), drying curves indicate that drying to a moisture content of approximately 30 percent, wet basis (w.b.), is a constant rate process. Beyond this point, internal movement of water controls the evaporation rate. Research (1, 10) has shown that drying of poultry manure to a moisture content of 30 percent w.b. is effective in reducing malodors and further moisture reduction produces increased dust problems (Figure 3.1). Therefore, the constant rate phase of drying is the area of principal concern in poultry manure drying and further discussion will be limited to this topic.

For constant rate drying, mass transfer of moisture is proportional to the exposed surface area, the difference in vapor pressure, and factors such as air velocity expressed as a mass transfer coefficient. Mathematically, the relationship between the above factors and the drying rate can be expressed in terms of the following heat or mass balance.

$$\frac{dW}{dt} = f_v A\ (P_s - P_a) = \frac{f_f(A)(t_d - t_s)}{h_{fg}} \tag{3.3}$$

where: dW/dt = drying rate, mass of water evaporated/time

f_v = water-vapor transfer coefficient at the water-air interface, mass/time-area-pressure

A = water surface area

P_s = saturation water-vapor pressure at t_s, pressure

P_a = water-vapor pressure in the drying air, pressure

f_f = thermal conductance of the air film at the water-air interface, energy/time-area-temperature

t_d = air temperature

t_s = water surface temperature

h_{fg} = latent heat of water at t_s, energy/mass

The water vapor transfer coefficient, f_v, can be regarded as the diffusivity of vapor through air (11). In the transfer of water vapor from the surface of a solid, the vapor must pass through a laminar layer of moist air before entering the adjacent turbulent zone as shown schematically in Figure 3.7. The value of f_v is a function of air velocity in combination with several other factors. Figure 3.7 also illustrates the decrease in water vapor pressure from the saturated air film immediately adjacent to the liquid surface to that of the surrounding air as previously discussed.

Equation 3.3 which is presented by Henderson and Perry (11) in a discussion of the drying of agricultural products is also discussed by Metcalf and Eddy (14) in relation to the drying of sewage sludge. Several factors should be noted in relation to Equation 3.3. First, the drying rate can be expressed as a function of either temperature or vapor pressure. This is due to the fact that saturation vapor pressure is a function of temperature. Second,

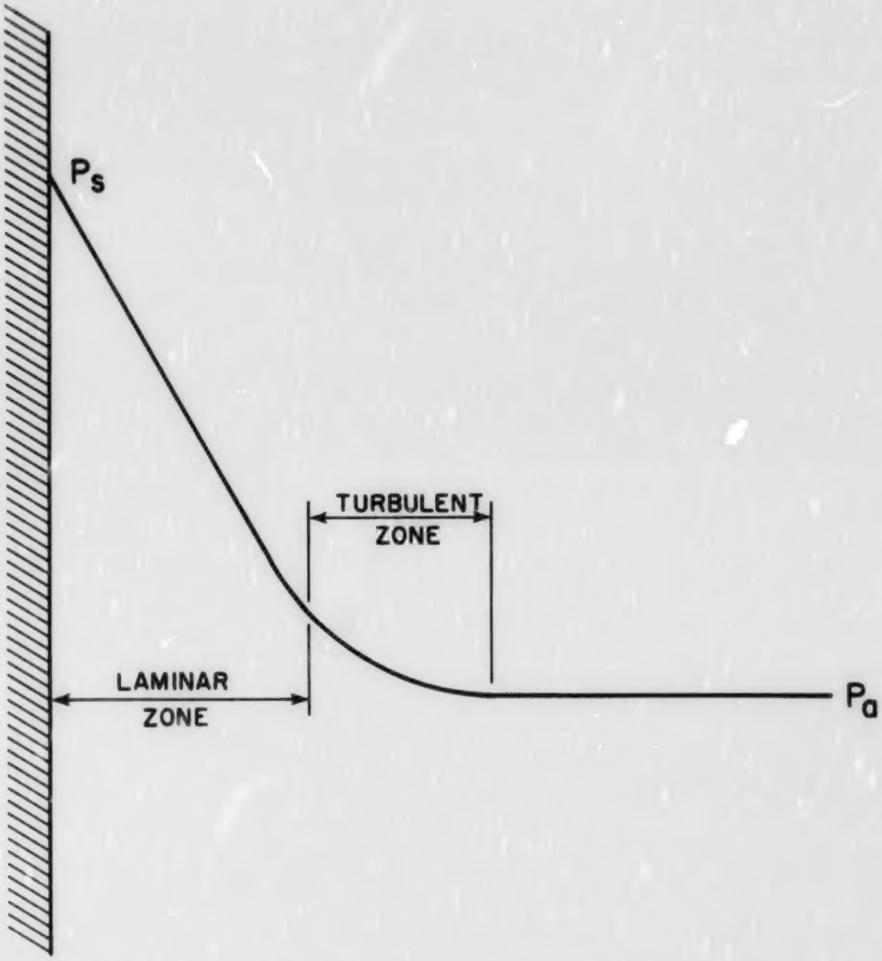
Ps
TURBULENT
ZONE
LAMINAR
ZONE
Pa

Figure 3.7. Change of partial pressure of water vapor with distance from surface for a constant drying-rate condition (after 11).

Equation 3.3 is merely a restatement of Dalton's law (Equation 3.1) if the heat relationship is excluded.

The theoretical concepts presented herein served as the basis for the development of a rational process design approach for high-rise house, undercage manure drying systems. Discussion of the development and presentation of the resulting process design equations will follow.

3.5 A Process Design Approach

Although the concept of high-rise, undercage poultry manure drying has been in existence for several years, a rational approach for the process design of these systems has been lacking. Design of existing systems has been arbitrary with performance ranging from marginal to excellent. Unfortunately, the lack of defined design relationships has precluded understanding of the reasons for success or failure and the opportunity to optimize system performance.

The results of a recently completed investigation by Sobel (15) have for the first time provided the basis for a rational design approach for these systems. The objectives of this system are:

A. Briefly describe the system studied;

B. Discuss the results of the investigation not only in terms of final waste characteristics but also the parameters identified as important to system performance;

C. Present the development of a design relationship expressing surface manurial moisture content as a function of the identified parameters;

D. Illustrate the relative importance of each variable to overall performance.

3.5.1 System Description

The high-rise drying system evaluated by Sobel (15) was located on a commercial poultry farm. The physical dimensions of the structure were 12.2 m wide by 102.4 m long (40 ft x 336 ft) with an egg handling area located at the one end of the building (Figure 3.4). The side wall height was 4.9 m (16 ft). This permitted location of the base of the manure collection and storage area slightly above grade.

The building had a design capacity of 30,000 hens contained in a flat deck cage system. Feed and egg handling was completely mechanized. A time clock controlled, continuous flow through-type watering system was used. The cages were located approximately 24 m (8 ft) above the base of the manure storage area. The base of the manure storage was 15 cm (6 in.) of fine cinders over soil.

Bird environment was controlled by 12 thermostatically controlled 91 cm (36 in.) exhaust fans placed in three banks of four fans located in the side wall of the manure storage area (Figure 3.3 and 3.4). Each fan delivered in excess of 4.5 m^3/sec (9500 ft^3/min) of air at a static pressure of 12.4 pascals (0.05 in. H_2O), gauge. Fresh air entered the building through manually controlled slot inlets located at the junction of the sidewall and roof. Within the manure storage area, eight fans were used to circulate ventilation air over the accumulated manure. Three fans (91 cm, 0.37 kw) were located along each side of the storage area and one fan (61 cm, 0.19 kw) was positioned for cross movement of air at each end of the storage area. This provided a circular pattern of air movement over the accumulated droppings. The pattern of air movement and location of the circulating fans are shown in Figures 3.3 and 3.4.

It should be noted that with the exception of the 4.9 m sidewall height, the location of the ventilation fans, and the presence of the circulating fans in the manure storage area, this building was designed in accordance with conventional practices employed in the northeastern United States. No special provisions regarding insulation or ventilation airflow rates were made.

3.5.2 Results

System performance throughout the three years of the study was excellent. At the end of each year at a time coinciding with flock replacement, the previous year's manure accumulation was removed. Average moisture content at the time of removal was 50, 50, and 47 percent, wet basis, respectively for each of the three years of the study (15). The absence of malodors was characteristic of both the accumulation and cleanout phases of operation. In addition, no problems were encountered using solid manure handling equipment such as front-end loaders and conventional manure spreaders for manure removal.

The parameter used to evaluate overall system performance was the moisture content of the ridge surface. This was determined from samples taken from the ridges of the manure accumulation such as in Figure 3.3. It was necessary to use this approach because the drying rate varied over time due to uncontrollable variables such as vapor pressure differential. Therefore, an accurate analytical determination of overall system moisture content during the accumulation phase was not possible. A summary of the data collected for the years 1970-71 and 1971-72 is presented in Table 3.1.

As shown in Equation 3.3, one of the variables affecting drying rate is surface area. Normally surface area would be constant. However, this is not true in a high-rise house manure drying system due to the formation of ridges and valleys which increase surface area with time. In order to quantify this variable, measurements of manure depths in ridges and valleys were made throughout the second year of this study. The results of these measurements were used to determine the increase in surface area over initial conditions. This increase was expressed as an area factor as follows:

$$\text{Area Factor} = \frac{\text{Distance Up and Down Ridges}}{\text{Width of Manure Storage Area}} \qquad (3.4)$$

TABLE 3.1. SUMMARY OF HIGH-RISE, UNDERCAGE MANURE DRYING DATA FOR 1970-71 AND 1971-72 (15).

1970-71

Cumulative Operation Time, Days	Bird Density, BD Birds/m^2	Area Factor* AF	Temperature, °C		Vapor Pressure		Vapor Pressure Differential	Drying Air Velocity, m/sec	Surface Moisture Content	
			Drying Air	Manure	Drying Air, P_a** pascals	Saturation, P_s*** pascals	(P_s-P_a), pascals		Dry Basis,%	Wet Basis,%
66	23.0	1.104	10(est)	10(est)	857	1224	367	0.5	253.3	71.7
								1.0	-	-
								1.5	196.7	66.3
87	22.4	1.137	8	9	766	1136	370	0.5	314.9	75.9
								1.0	207.7	67.5
								1.5	236.7	70.3
128	21.4	1.203	10.5	11	889	1318	429	0.5	263.6	72.5
								1.0	178.6	64.1
								1.5	131.5	56.8
195	20.6	1.310	24	22	2068	2671	603	0.5	134.7	57.4
								1.0	119.3	54.4
								1.5	90.1	47.4
248	20.3	1.395	21.5	25	1808	3158	1350	0.5	123.2	55.2
								1.0	72.4	42.0
								1.5	29.2	22.6
328	19.6	1.523	14	28	1107	3720	2613	0.5	141.5	58.6
								1.0	40.6	28.9
								1.5	30.5	23.4

*Calculated from regression equation AF - 0.0016 (cumulative time of operation, days) + 0.998

**P_a is the vapor pressure of the drying air at the observed temperature of the storage air of a relative humidity of 70%. Relative humidity was not measured at each sampling event and was assumed to be 70%, a value observed in several measurements.

***P_s is the saturation vapor pressure of air at a temperature equal to that of the manure.

TABLE 3.1. SUMMARY OF HIGH-RISE, UNDERCAGE MANURE DRYING DATA FOR 1970-71 AND 1971-72 (15) (CONTINUED).

Cumulative Operation Time, Days	Bird Density, BD Birds/m^2	Area Factor* AF	Temperature, °C		Vapor Pressure		Vapor Pressure Differential $(P_s - P_a)$, pascals	Drying Air Velocity m/sec	Surface Moisture Content	
			Drying Air	Manure	Drying Air, P_a** pascals	Saturation, P_s*** pascals			Dry Basis, %	Wet Basis, %
					1971-72					
59	25.4	1.092	14	13	1148	1526	378	0.5	230.0	69.7
								0.7	266.3	72.7
								1.3	219.5	68.7
86	25.0	1.136	11	11	922	1318	396	0.5	257.1	72.0
								0.7	192.4	65.8
								1.3	198.5	66.5
116	24.4	1.184	12.5	14.5	1038	1640	602	0.5	258.4	72.1
								0.7	232.2	69.9
								1.3	172.5	63.3
143	24.1	1.227	11.5	15	957	1700	743	0.5	177.0	63.9
								0.7	187.4	65.2
								1.3	133.1	57.1
184	23.8	1.292	11.5	15.5	957	1761	804	0.5	175.5	63.7
								0.7	142.1	58.7
								1.3	81.2	44.8
213	23.5	1.339	26.5	24.5	2440	3055	615	0.5	126.8	55.9
								0.7	61.3	37.9
								1.3	-	-
240	23.2	1.382	20.5	23.5	1688	2858	1170	0.5	84.2	45.7
								0.7	-	-
								1.3	-	-
267	23.0	1.425	29	32	2776	4802	2024	0.5	116.9	53.9
								0.7	115.0	53.5
								1.3	68.6	40.7
305	22.7	1.486	22	30.5	1870	4368	2498	0.5	74.8	42.8
								0.7	71.2	41.6
								1.3	61.0	37.9
339	22.4	1.540	21	30	1747	4231	2484	0.5	126.8	55.9
								0.7	103.7	50.9
								1.3	102.4	50.6
355	22.3	1.566	14	28	1107	3720	2613	0.5	102.4	51.1
								0.7	94.9	48.7
								1.3	44.5	30.8

*Calculated from regression equation AF = 0.0016 (cumulative time of operation, days) + 0.998.

**P_a is the vapor pressure of the drying air at the observed temperature of the storage air of a relative humidity of 70%. Relative humidity was not measured at each sampling event and was assumed to be 70%, a value observed in several measurements.

***P_s is the saturation vapor pressure of air at a temperature equal to that of the manure.

The observed change in area factor with time for the 1971-72 laying cycle is presented in Figure 3.8.

Air velocity was not uniform over the accumulated manure surface due to the nature of the air stream from the circulating fans and the irregular manure surface (Figure 3.6). The velocity of the airstream decreased with distance from the fan but the width of the stream increased. Observed velocities at various locations in the manure storage area ranged from 0 to 2 m/sec (0 to 400 ft/min). To develop an understanding of the relationship between air velocity and moisture removal, surface moisture contents were determined at sites exposed to three different air velocities over time. The velocities selected were 0.5, 1.0, and 1.5 m/sec (100, 200 and 300 ft/min) in 1970-71 and 0.5, 0.7 and 1.3 m/sec (100, 140 and 250 ft/min) in 1971-72. While velocity varied as to location within the manure storage area, variation was not significant with time. Therefore, samples for surface moisture content determinations were taken at set locations and velocity was considered constant over time at each location. Tabulated values are presented in Table 3.1. The observed relationships between moisture content at sites exposed to different air velocities and cumulative time of operation are shown in Figures 3.9 and 3.10. As shown, moisture content decreases with time of operation with air velocity remaining constant. This illustrates that moisture removal is a function of several factors, not only air velocity.

Temperatures of the drying air in the manure storage area as well as in the accumulated manure near the surface were measured continuously during 1970-71 and 1971-72. Data for temperature corresponding to each moisture content sampling event are presented in Figures 3.11 and 3.12. During 1970-71, the temperature differential over the first 200 days of operation was minimal. Following that time period a significant differential occurred. The same general pattern was repeated during 1971-72. The increase in manurial temperature over the temperature of the drying air was attributed to biological heat production.

Drying in general is a physical treatment process which provides odor control by limiting microbial activity through the removal of water. Reduction of the moisture content of poultry wastes to 10 to 15 percent, wet basis, has been reported to inhibit microbial growth (10). However, observed manurial moisture contents (Table 3.1) did not approach this range of values. The conclusion that microbial activity was not measurably limited is supported by the observed biological heat production. Microbial heat production is a manifestation of the inefficiency in the transformation of a substrate into energy for synthesis and maintenance. The absence of malodors suggests that the microbial activity was predominately aerobic.

Drying air and manurial surface temperatures were used to determine the vapor pressure differential at each sampling event. Saturation vapor pressure values were obtained from standard tables of the thermodynamic properties of moist air (16). The vapor pressure of the drying air was determined from saturation values at the observed temperature and an assumed relative humidity of 70 percent. Relative humidity was not measured at each sampling event; the assumed value of 70 percent was observed on several occasions.

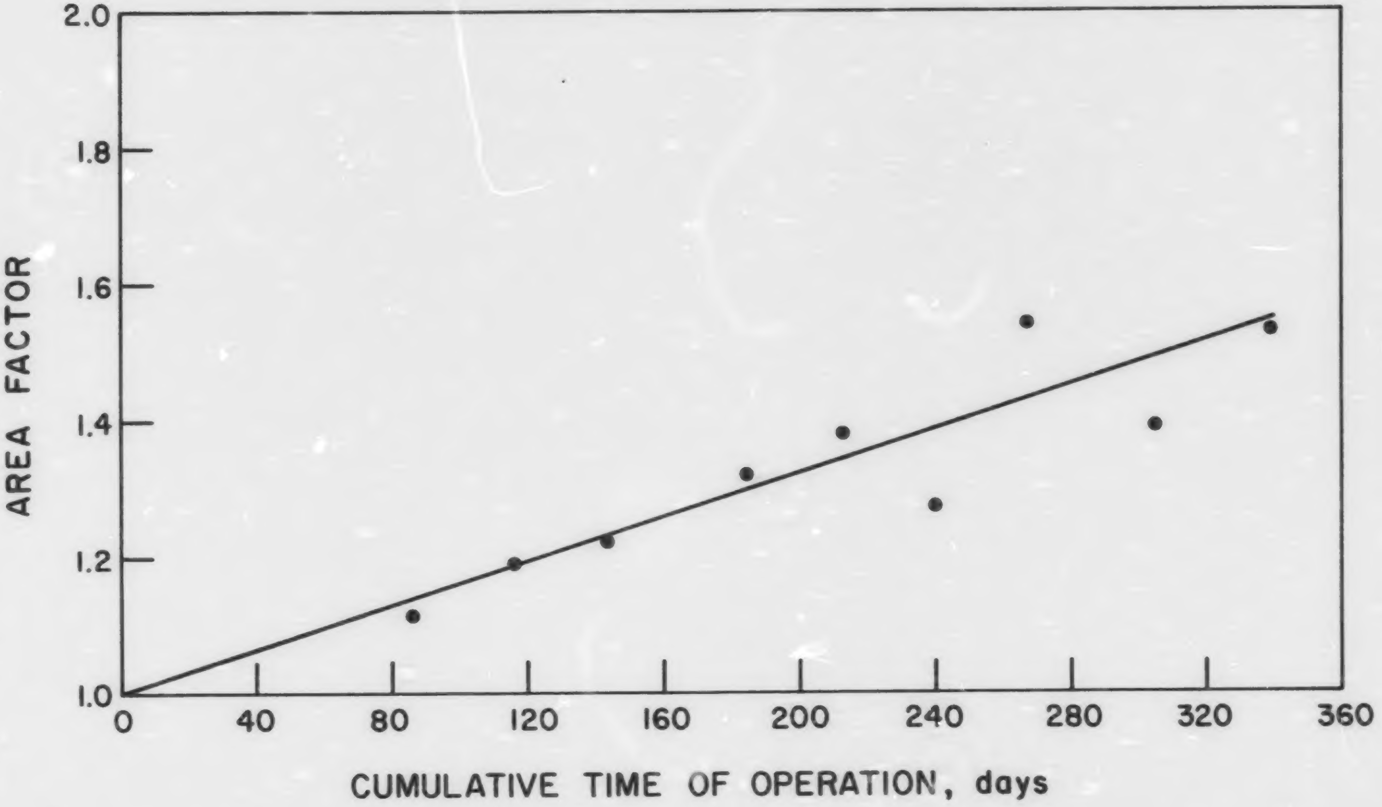

Figure 3.8. Area factor as a function of cumulative time of operation, 1971-72 (15).

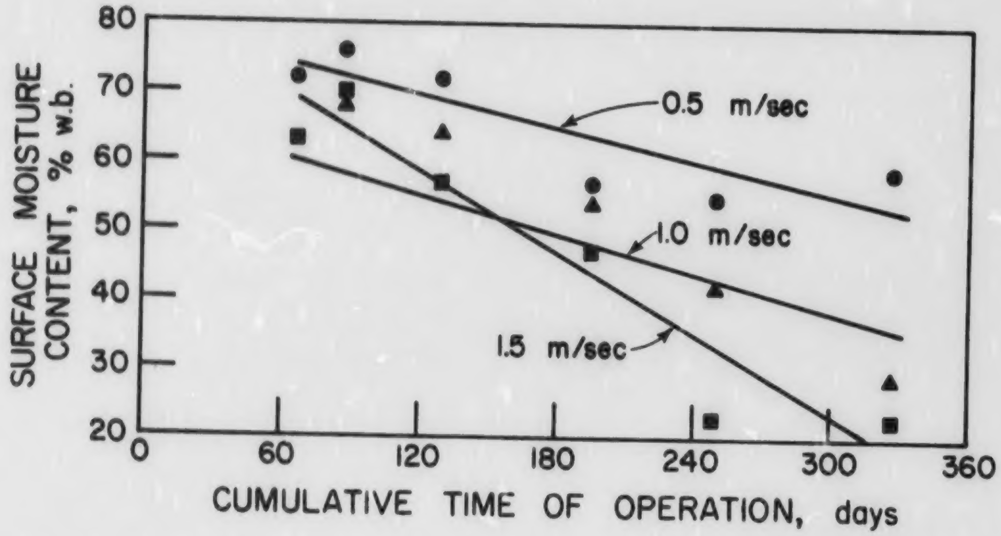

Figure 3.9. Moisture content as a function of operation time, 1970-71 (15).

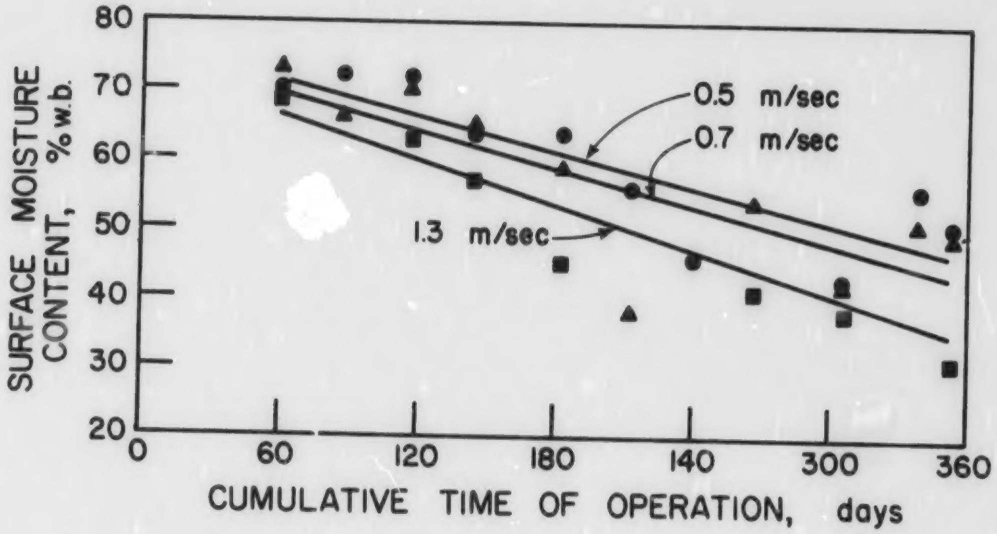

Figure 3.10. Moisture content as a function of operation time, 1971-72 (15).

The change in observed vapor pressure differential with time for the years 1970-71 and 1971-72 are shown in Figure 3.13. The significant increase in vapor pressure differential following the first 200 days of operation for both years is the result of the increase in the temperature differential resulting from biological heat production (Figures 3.11 and 3.12). Since vapor pressure differential is the principal driving force for moisture removal (Equation 3.1 and 3.3), it appears that biological heat production which results in higher saturation vapor pressures at the manure surface is an important factor in high-rise, undercage drying. However, definition of the environmental conditions which enhance biological heat production in these systems and thus the ability to control and predict this phenomenon is lacking at this time.

3.6 Development of a Process Design Relationship

A mathematical understanding of moisture removal in the high-rise, undercage drying system is necessary to the development of a rational design approach. However, direct application of a relationship such as Equation 3.3 is not possible. Information concerning the water-vapor transfer coefficient, f_v, for poultry manure is lacking. Therefore, an emperical approach was used to develop a mathematical model of this drying system utilizing the theoretical concepts previously discussed. Data collected during the previously described three year study was used.

For the high-rise drying system, the average drying rate for the constant rate drying phase over time, $d\overline{W}/dt$, can be expressed in terms of the initial moisture content, M_o, of the manure measured on a dry basis, the system moisture content, M_t, at any time t measured on a dry basis and the production of total solids, P, over time t.

$$\frac{d\overline{W}}{dt} = (M_o - M_t)\,P \qquad (3.4)$$

where: $d\overline{W}$ = average drying rate over time t, mass of water evaporated/time

M_o = initial moisture content of the manure, mass of water/mass of total solids, measured on a dry solids basis

M_t = average system moisture content at any time t, mass of water/mass of total solids, measured on a dry solids basis

P = production of total solids, mass/time

As shown in the preceding section, the variables affecting the drying rate, and therefore the drying rate, vary with time. For example, the area factor, AF, increases while bird density due to mortality decreases with time (Table 3.1 and Figure 3.8). During both 1970-71 and 1971-72, the vapor

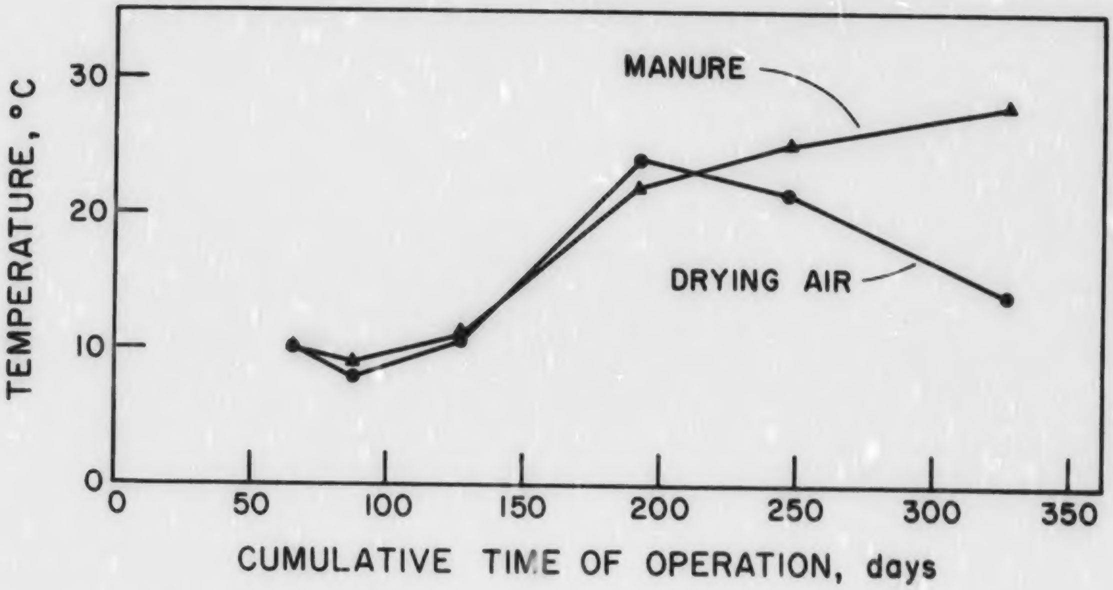

Figure 3.11. Manurial surface and drying air temperatures, 1970-71 (15).

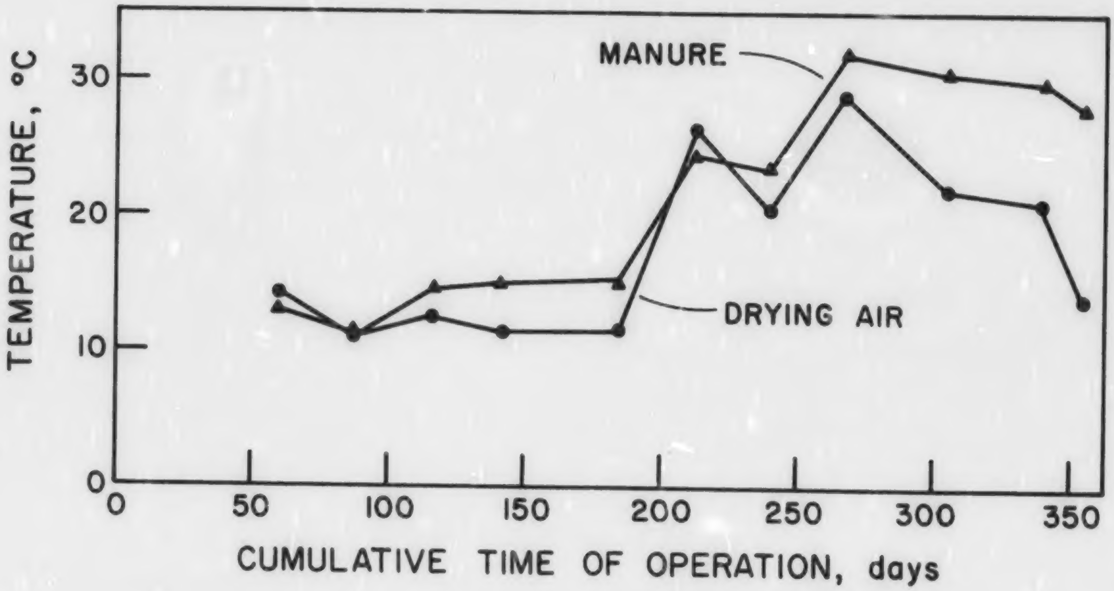

Figure 3.12. Manurial surface and drying air temperatures, 1971-72 (15).

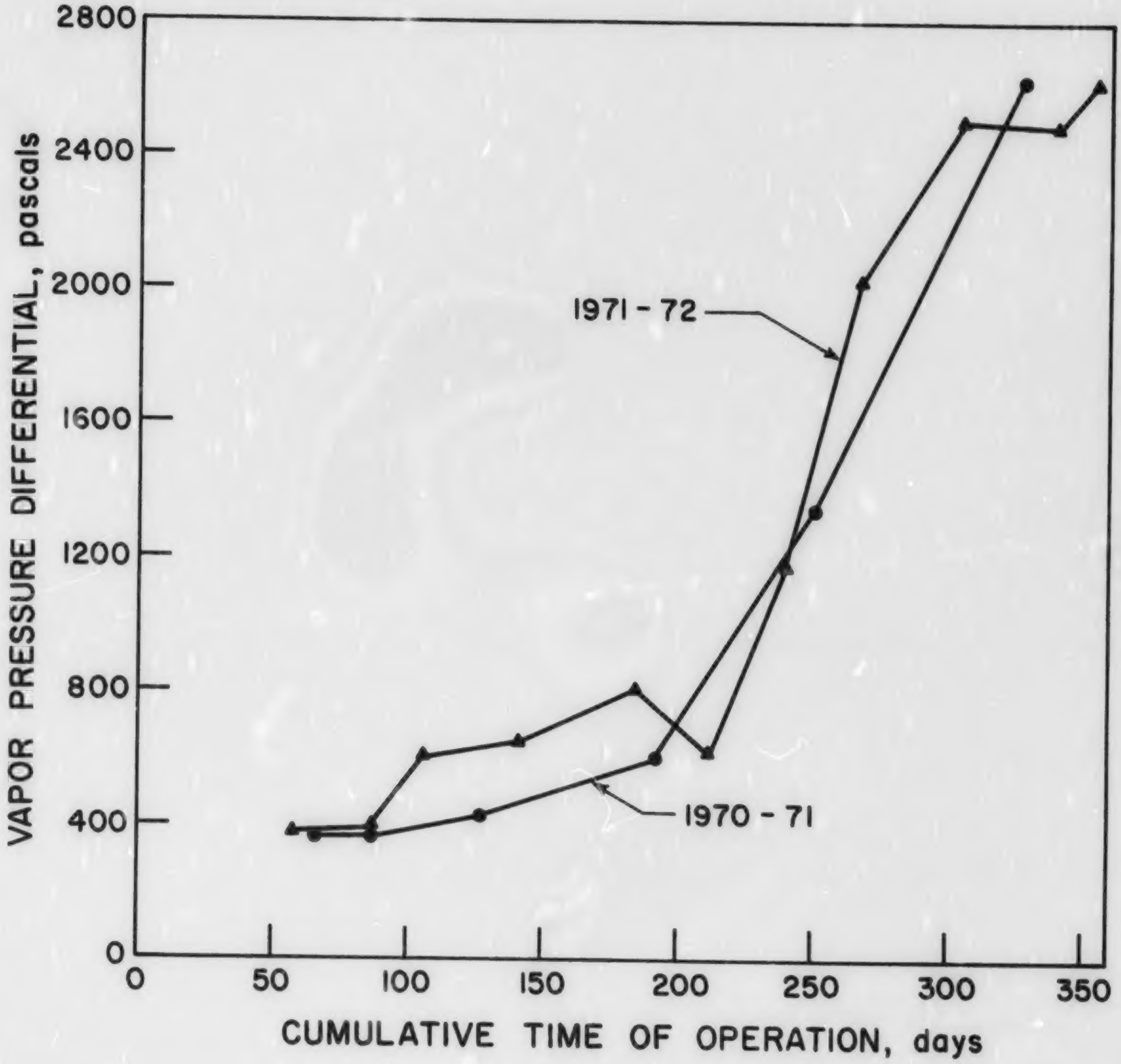

Figure 3.13. Change in vapor pressure differential with time of operation (15).

pressure differential increased with time but differed between the two years (Figure 3.13). Moreover, air velocity differs with location due to the nature of the air stream from the circulating fans. Thus, system moisture content at any specific time can not be predicted and is difficult to measure except upon removal and complete mixing of the accumulated manure.

However, it is possible to determine the surface moisture content of the accumulated manure and define the relationship between surface moisture content and the values of the variables affecting the drying process. For the high-rise, undercage drying process, this approach is meaningful in that the time of surface area exposure for a discrete quantity of manure and thus the opportunity for evaporation is limited by new manure deposition creating a new surface. System moisture content is simply the summation of surface moisture contents over time.

The manurial surface moisture content at any time, t, can be expressed mathematically as a function of the variables affecting moisture removal as follows:

$$M_{sf} = f\left[\left(\frac{AF}{BD}\right), V, (P_s - P_a)\right] \qquad (3.5)$$

where: M_{sf} = manurial surface moisture content, dry basis, mass of water/mass of total solids - percent

AF = area factor, dimensionless

BD = bird density per unit of manure collection area, birds/m^2

V = velocity of the drying air, m/sec

P_s = saturation water vapor pressure at the temperature of the manure surface, pascals

P_a = water vapor pressure in the drying air, pascals

Sobel (15) utilized the data presented in Table 3.1 to determine the mathematical relationship between M_{sf} and the variables in Equation 3.5. Initially, the correlation between each variable (AF/BD, V, and $P_s - P_a$) individually with M_{sf} was examined. However, this approach was unsuccessful. Examination of the correlation between the product of V and $P_s - P_a$ reduced variation and indicated that a non-linear relationship existed between (V), ($P_s - P_a$) and M_{sf}. Multiplication by the area factor-bird density ratio, AF/BD, improved the correlation, and it was found that the relationship was of the form $Y = aX^b$ with X defined as:

$$X = \left[\left(\frac{AF}{BD}\right)(V)(P_s - P_a)\right] \qquad (3.6)$$

Thus, Equation 3.5 can be restated as:

$$M_{sf} = aX^{b} \tag{3.7}$$

Regression analysis was used to determine the values for the coefficient a and the exponent b. This produced the following relationship (Figure 3.14):

$$M_{sf} = 800\ X^{-0.494} \tag{3.8}$$

To verify the accuracy of Equation 3.8 in predicting surface moisture content under specific conditions, this equation was used to calculate values for manurial surface moisture content at the beginning and end of the 1971-72 manure accumulation cycle. These predicted values were compared with the average of observed values determined during removal of the accumulated manure. Surface samples from various locations were composited to establish an average surface moisture content at the end of the manure accumulation cycle. Moisture values determined from samples taken at the bottom of the manure accumulation were used to estimate the average surface moisture content at the begining of the accumulation cycle. It appears reasonable to use moisture values at the bottom of the accumulated manure as representative of initial conditions in that the major evaporation of moisture occurs at the manurial surface.

Predicted values for manurial moisture contents at the begining and end of the 1971-72 manure accumulation cycle are presented in Table 3.2. Average values for the variables defining surface moisture content (Equation 3.6) and the observed moisture content values are also included.

The predicted value of 317 percent, wet basis (76 percent dry basis) was in good agreement with the average moisture content observed at the bottom of the manure accumulation of 276 percent, dry basis (73 percent, wet basis) (Table 3.2). The predicted surface moisture at the end of the manure accumulation cycle was 99 percent, dry basis (50 percent, wet basis). Again the agreement between the predicted and observed values was reasonable suggesting the validity of Equation 3.8. It is recognized that these comparisons between predicted and observed results are not entirely independent, since values used in the comparisons also were used in the development of Equation 3.8. Unfortunately, no independent data was available.

One limitation of Equation 3.8 is that the variable bird density (BD) (Equation 3.6) does not permit introduction of the quantity of moisture excreted per bird-day as a variable. Bird density is an indirect expression of the mass of water excreted per unit area of manure storage per day. This is based on a single value for mass of water excreted per bird-day and thus has a fixed upper limit. As discussed in Chapter 2, moisture excretion appears to be a function of feed characteristics. Therefore, it is possible to have a higher moisture loading per unit area per day, with higher values of moisture excreted per bird-day. In the study by Sobel (15), the moisture excreted per bird-day was 99 gm. A bird density of 20 birds/m^2 of manure collection area resulted in a maximum moisture loading of 1980 gm H_2O/m^2. If feed characteristics increased moisture excreted to 110 gm H_2O/bird-day,

TABLE 3.2. COMPARISON OF PREDICTED AND OBSERVED MOISTURE CONTENTS AT THE BEGINNING AND END OF THE 1971-72 MANURE ACCUMULATION CYCLE

	Area Factor	Bird Density, birds/m^2	Average Velocity, m/sec	Average Vapor Pressure Differential, Pa	X, $(\frac{m^2}{bird})(\frac{m}{sec})(Pa)$	M_{sf},* Dry Basis	M_{sf},† Dry Basis
Initial	1.0	26.9	0.40	439	6.53	317	276
Final	1.5	21.5	0.59	1688	69.49	99	77

* Predicted value
† Observed value

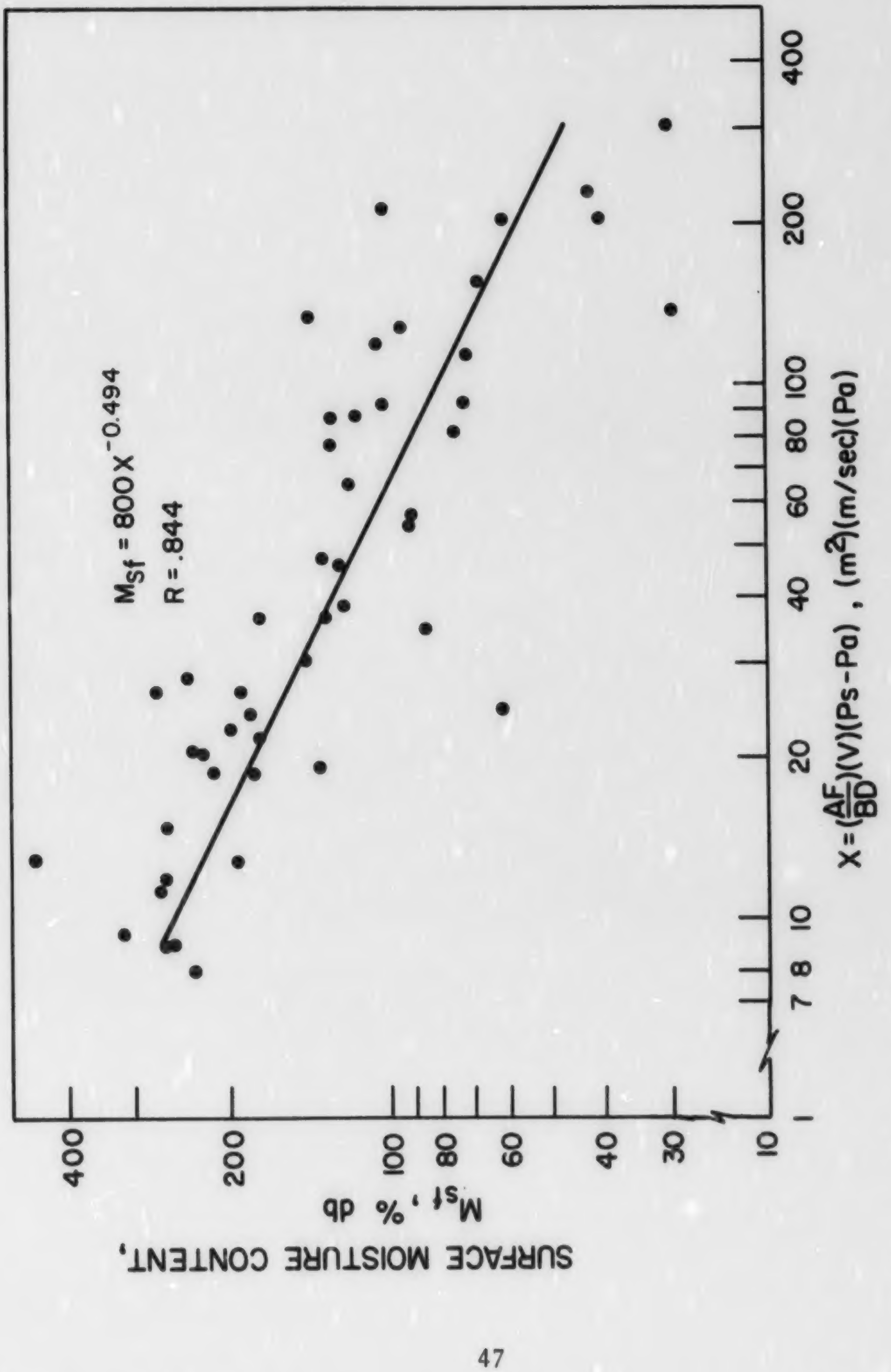

Figure 3.14. Development of surface moisture content predictive equation.

maximum moisture loading would be 2200 gm H_2O/m^2. Therefore, if the evaporation rate remained fixed, resulting moisture contents would be higher but not predicted by Equation 3.8.

Therefore, Equation 3.6 was modified by substituting a moisture loading factor for bird density. The moisture loading factor combines bird density and manure characteristics.

$$MLF = (BD)(MP) \tag{3.9}$$

where: MLF = moisture loading factor, kg H_2O/m^2-day

BD = bird density, birds/m^2

MP = moisture excreted, kg H_2O/bird-day

In order to provide a more precise basis for calculation of bird density, bird density as used in Equation 3.9 is based on cage row width instead of width of the manure accumulation area. The reason for this change will be described in detail in the following section on process design methodology.

Regression analysis was again used to determine the values of a and b for Equation 3.7 with X redefined as:

$$X' = \left[\left(\frac{AF}{MLF}\right)(V)(P_s - P_a) \right]$$

This produced the following relationship (Figure 3.15):

$$M_{sf} = 2271\ X'Y\text{-}0.494$$

The development of a mathematical expression defining the relationship between moisture content and the associated variables (Equation 3.11) permits the assessment of the relative importance of each variable. A short computer program (The Appendix, Figure A-1) was written to examine the relative importance of each variable in relation to the resultant manure surface moisture content. This was done by calculation of simulated moisture contents over a range of values for a selected variable holding the other variables constant. Values selected for the area factor, air velocity at the manure surface, and vapor pressure differential are representative of conditions observed by Sobel (15). In the analysis of the effect of the moisture loading factor, two values were used for the quantity of moisture excreted per bird-day. They are 81 and 135 gm H_2O/bird-day reflecting high and low energy feeding programs (Chapter 2). Both values were varied over a simulated decrease in bird density due to mortality of 117.9 to 87.3 birds/m^2. The range of values and assumed constant values for each variable are presented in Table 3.3.

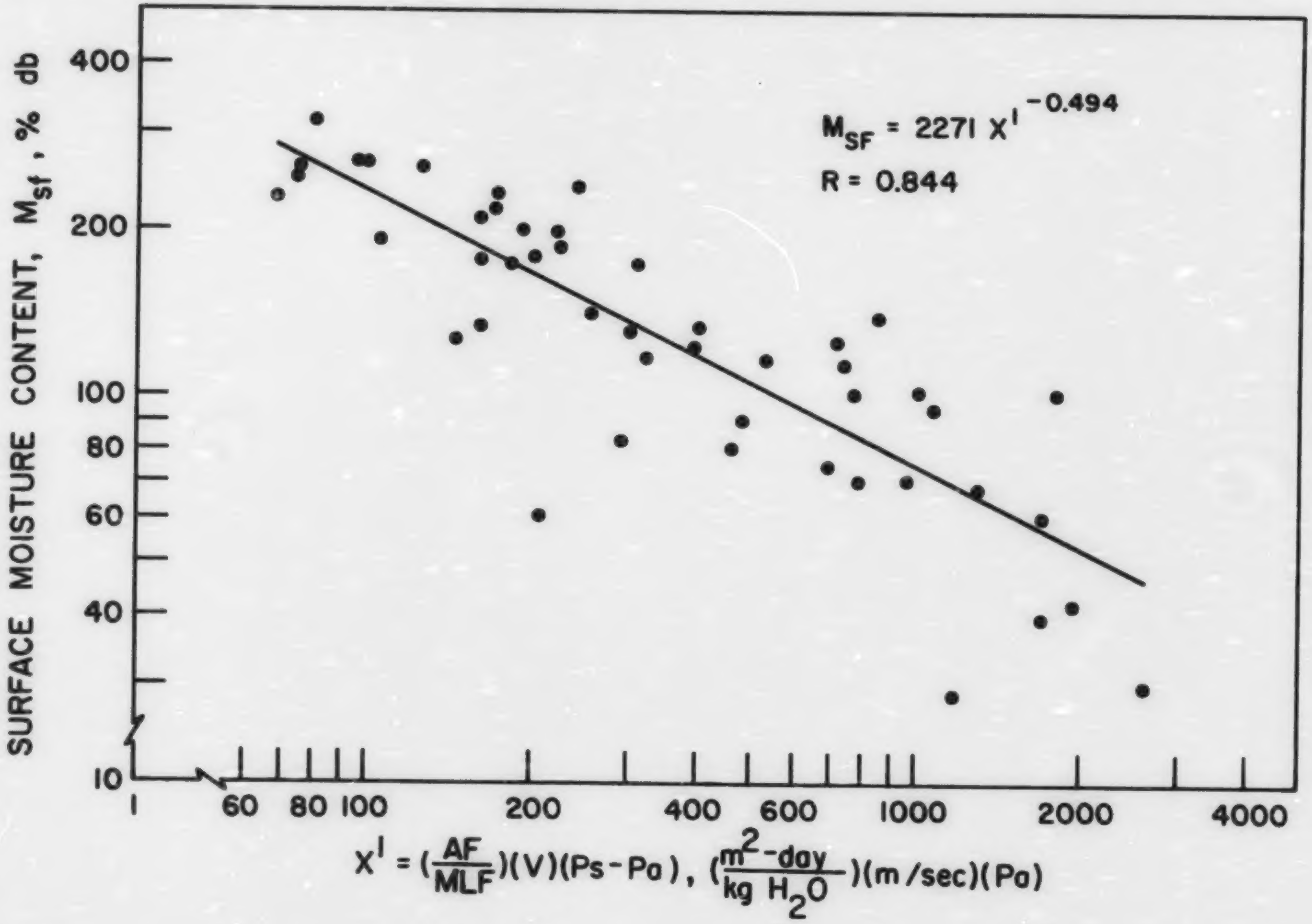

Figure 3.15. Redefinition of surface moisture content predictive equation.

TABLE 3.3. VALUES USED IN THE SIMULATION OF HIGH-RISE DRYING

Parameter	Value Used as a Constant When Other Parameters Were Varied	Range of Values as a Variable
Area Factor, dimensionless	1.3	0.9 -1.6
Moisture loading factor, kg H_2O/m^2-day	2.06	1.76-3.9
Air velocity, m/sec	0.5	0.25-2.0
Vapor pressure differential, pascals	1360	100-2720

The results of the simulations are presented in Figures 3.16 through 3.19. Before considering the results of these simulations, it should be recognized that while the moisture loading factor and air velocity are controllable variables, the area factor and the vapor pressure differential are not controllable in a high-rise drying system.

Of the four variables, the increase in area factor due to ridge formation appears to have the least effect on manurial surface moisture content (Figure 3.16). The increase of AF from 1.0 to 1.6 reduced the surface moisture content by only 5.85 percent in the simulation. The magnitude of this change is similar to that which results from the reduction of bird density due to mortality over the laying cycle.

The response to decrease in bird density was found to be a 1.9 and 2.0 percent reduction in surface moisture content respectively for birds excreting 135 and 81 gm H_2O/bird-day (Figure 3.17). Of greater significance is the difference in the predicted surface moisture content between birds with high versus low quantities of water excreted per day. This difference was 6.1 percent at the maximum bird density of 117.9 birds/m^2 (Figure 3.17).

The simulation results showed that the variables of greatest importance are air velocity and vapor pressure differential. Increasing air velocity from 0.25 to 2.0 meters per second reduced predicted surface moisture content by 25.2 percent (Figure 3.18). The sensitivity of surface moisture content was even greater with a reduction of 35 percent when the vapor pressure differential increased from 100 to 2720 pascals (Figure 3.19).

Recognition of the relationships between air velocity and vapor pressure differential and resultant surface moisture content is important. In systems with no external heat added, large vapor pressure differentials can only be

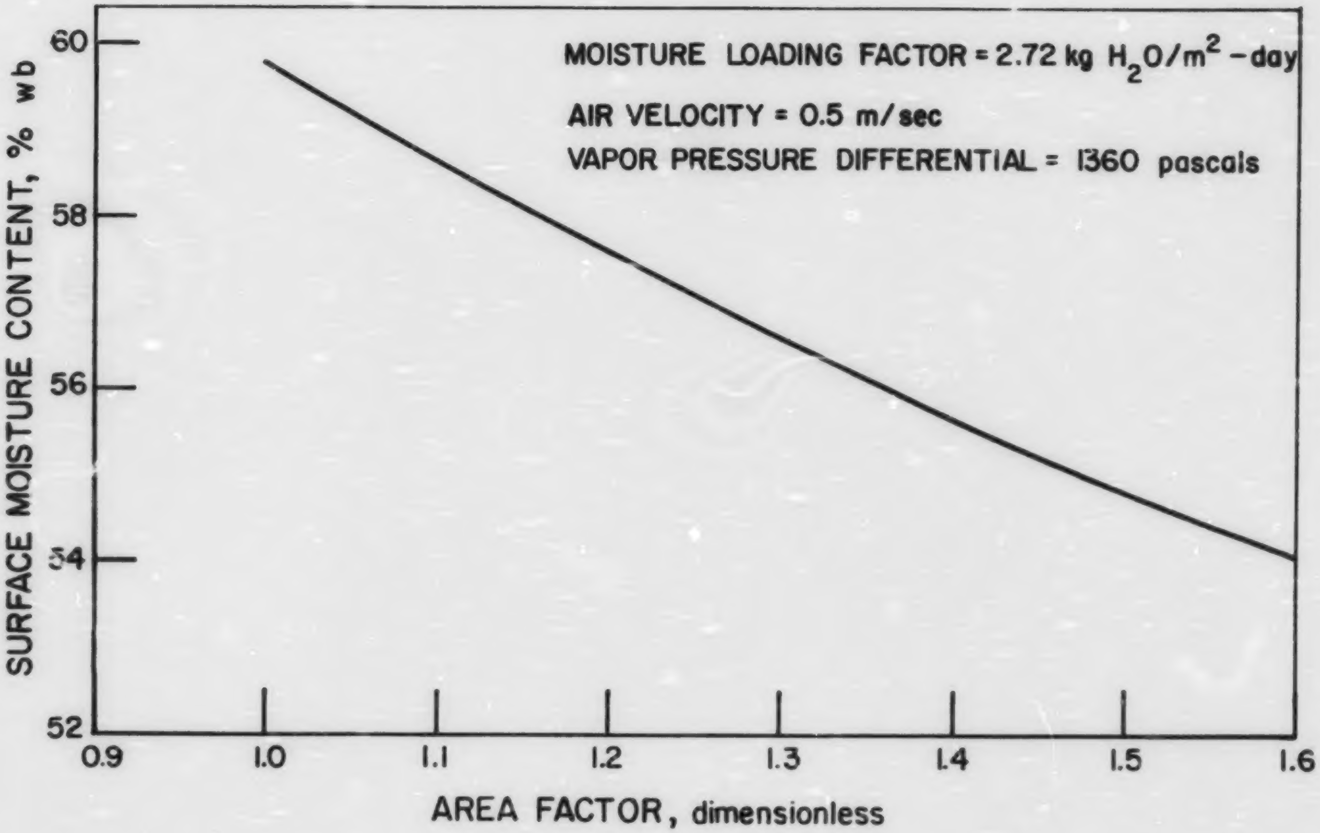

Figure 3.16. Relationship between area factor and surface moisture content.

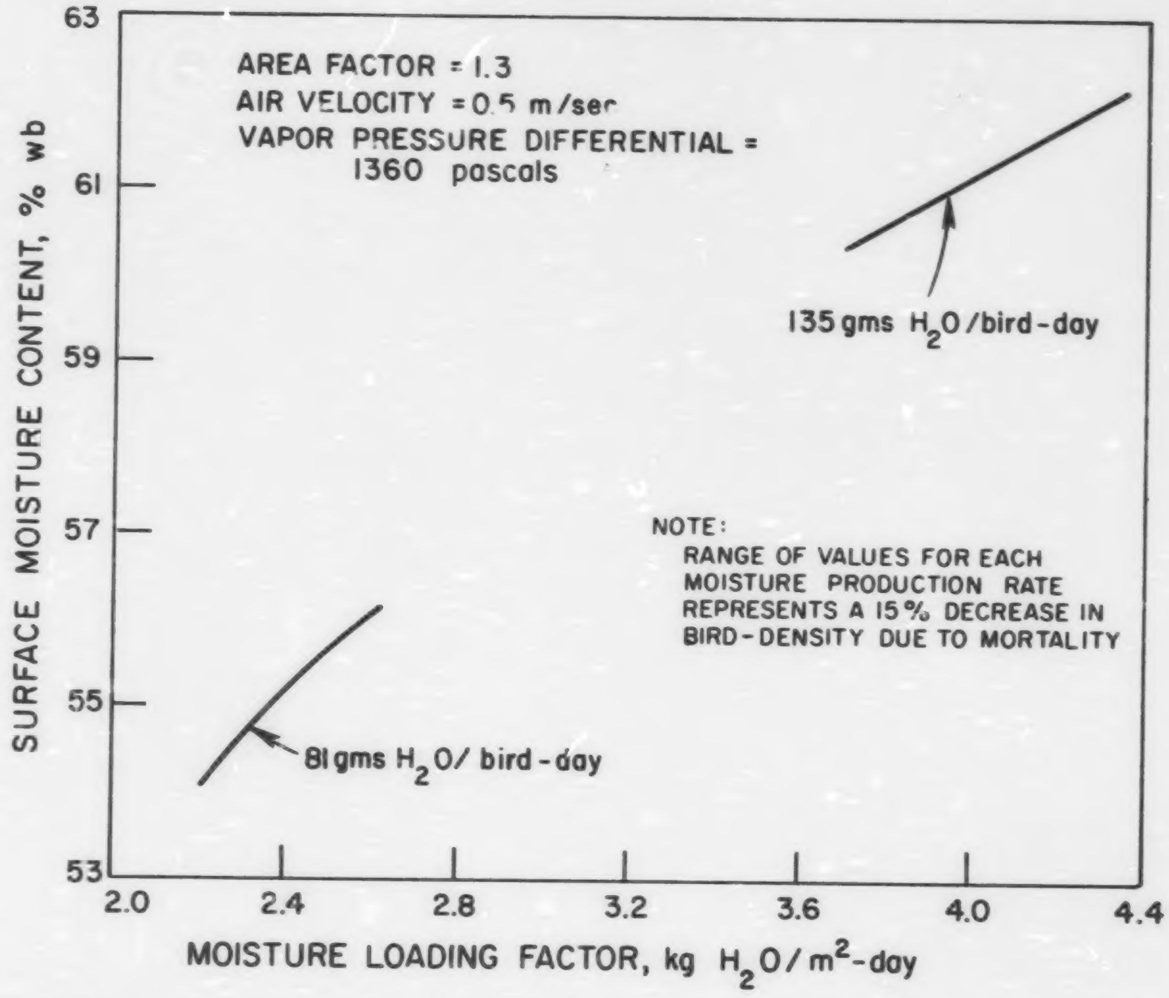

Figure 3.17. Relationship between moisture loading factor and surface moisture content.

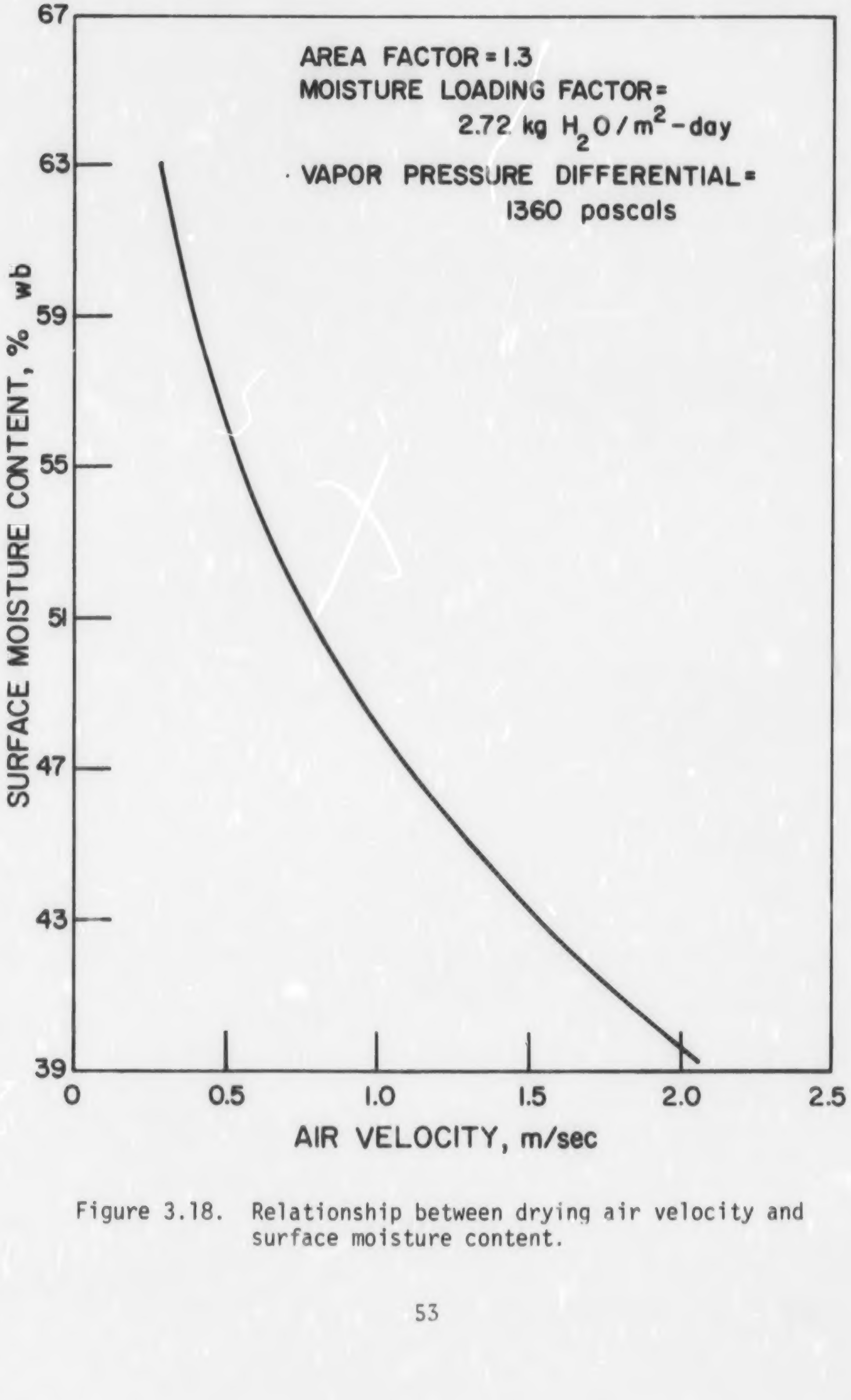

Figure 3.18. Relationship between drying air velocity and surface moisture content.

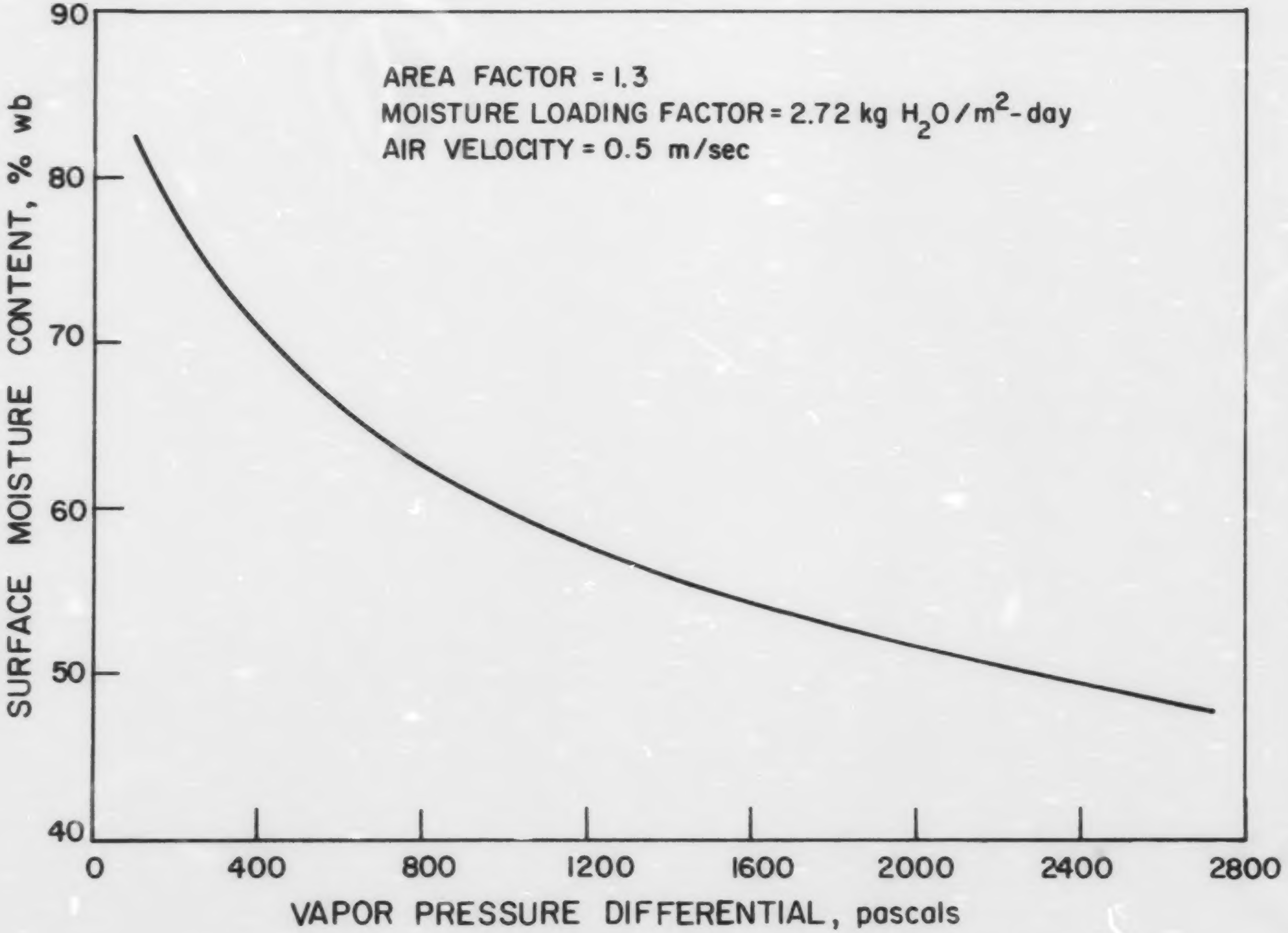

Figure 3.19. Relationship between vapor pressure differential and surface moisture content.

achieved through biological heat production in the accumulated manure. While this production does occur and will be a positive factor in moisture reduction, it is uncontrollable. Thus, increasing air velocity is the principal process design variable that can be controlled to achieve low moisture content poultry manure in a high-rise poultry manure drying system. Another significant factor is to use birds and feed that reduce the moisture content of the excreted manure to as low a value as possible.

3.6 Process Design Methodology

The mathematical relationships, Equations 3.9 through 3.11, provide the basis for a rational design approach for high-rise, undercage drying systems for poultry wastes. However, utilization of the predictive relationship, Equation 3.11, as a process design tool requires an understanding of several factors. Included are available types of cage systems, management practices, and the nature of the high-rise drying process. Such an understanding is necessary in order that the limitations of currently available process design methodology are recognized. Therefore, the objectives of this section are to:

A. Discuss available types of cage systems and management practices as related to bird density and therefore, the moisture loading factor;

B. Present the development and discuss the application of a high-rise process design relationship;

C. Presentation of a suggested process design methodology.

3.6.1 Available Cage Systems and Management Practices as Related to Bird Density and the Moisture Loading Factor

As illustrated in Section 3.5, the moisture loading factor (MLF) has a significant effect on high-rise drying performance as measured by the manurial surface moisture content. The MLF is a function of two variables, waste characteristics and bird density (Equation 3.9). The relationship between feeding practices and the quantity of moisture excreted per bird-day has been discussed in Chapter 2. There are two factors that can cause variation in bird density: a) the type of cage system, and b) the number of birds per cage.

There are three types of cage systems which are used in commercial egg production. They are the flat deck, full stair-step, and triple deck cage systems. A cross-sectional view of each is presented in Figure 3.20. Two standard cage sizes, 30 cm x 51 cm or 61 cm x 51 cm, are available with each cage system. Average cage height is 42 cm. The smaller cages are used for either 4 or 5 hens while the larger cages are used to contain 8 to 10 hens depending on management practices. Thus, bird density can vary significantly. Details are presented in Table 3.4.

In practice, the area of manure accumulation is somewhat larger than the cage area. However, there is a constant relationship between these two factors, and in this design approach (Equations 3.9 through 3.11) bird density is based on cage floor area rather than manure accumulation area. Since no overlap of

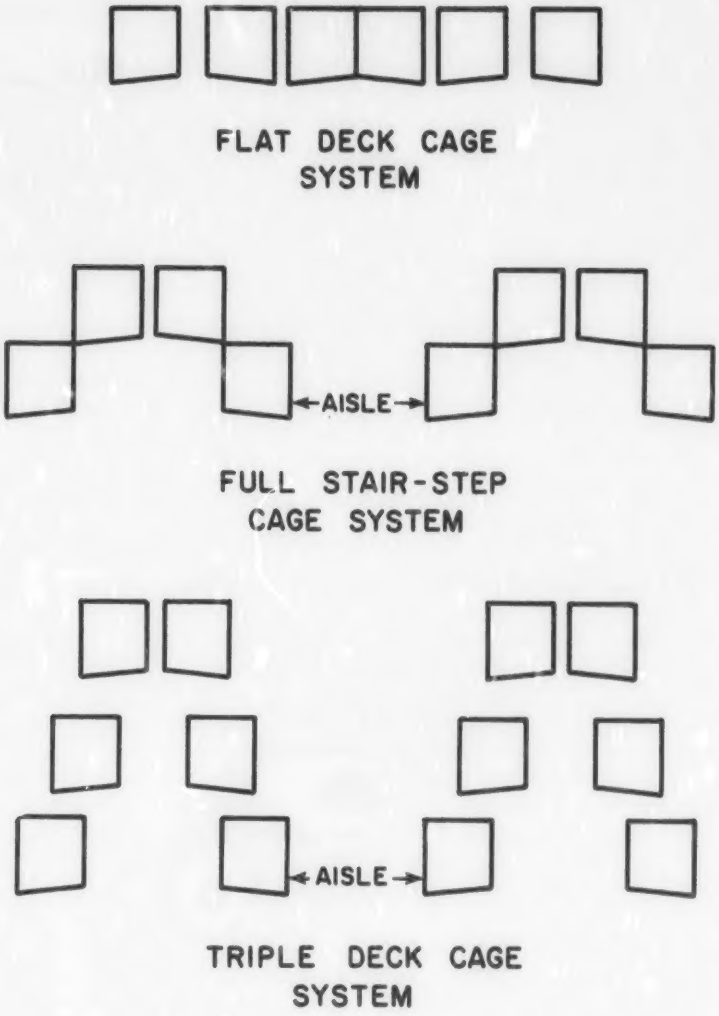
FLAT DECK CAGE SYSTEM
AISLE
FULL STAIR-STEP CAGE SYSTEM
AISLE
TRIPLE DECK CAGE SYSTEM

Figure 3.20. Cross-sectional views of the three predominate types of cage systems for laying hens.

TABLE 3.4. RANGES OF BIRD DENSITY PER UNIT CAGE FLOOR AREA WITH DIFFERENT MANAGEMENT PRACTICES

Cage Dimension, cm	Area, m^2	No. of Birds/Cage	Density, Birds/m^2
30.5 x 50.8	0.15	4	25.8
30.5 x 50.8	0.15	5	32.3
61.0 x 50.8	0.31	8	25.8
61.0 x 50.8	0.31	9	29.1
61.0 x 50.8	0.31	10	32.3

cages occurs with the flat deck and full stair-step cage systems, the values for bird density, presented in Table 3.4 can be used directly in the calculation of the moisture loading factor (Equation 3.9).

With the triple deck cage system, the overlap of cages (Figure 3.20) results in a higher bird density based on cage row width than in terms of cage floor area. Bird densities for this type of cage system based upon cage row width are presented in Table 3.5.

TABLE 3.5. RANGES OF BIRD DENSITY BASED ON CAGE ROW WIDTH FOR TRIPLE DECK CAGE SYSTEMS

Cage Dimension, cm	Area, m^2	No. of Birds/Cage	Density, Birds/m^2
30.5 x 50.8	0.15	4	31.8
30.5 x 50.8	0.15	5	39.8
61.0 x 50.8	0.31	8	31.8
61.0 x 50.8	0.31	9	35.8
61.0 x 50.8	0.31	10	39.8

The ranges in values presented in Tables 3.4 and 3.5 illustrate the importance of defining the type of cages to be used and anticipated management practices as the first step in high-rise, undercage drying system design.

3.6.2 Development and Application of a High-Rise Drying Process Design Relationship

The discussion of the high-rise, undercage drying process has focused on the development of a predictive relationship (Equation 3.11). This relationship defines the manurial surface content as a function of four variables; area factor (AF), moisture loading factor (MLF), drying air velocity (V), and the vapor pressure differential (VPD). The transformation of Equation 3.11 into a process design equation and its subsequent use depends on an understanding of the nature of the variables involved.

Of the four variables in Equation 3.11, two variables, AF and VPD, represent uncontrollable parameters. Moreover, a lack of understanding of the causes of change over time results in the inability to predict these changes. While a specified value can be designated or determined for MLF, it also is a variable in the high-rise drying process which will decrease with time due to bird mortality. Under normal conditions, a mortality rate of approximately one percent per month can be expected.

In contrast, the velocity of the drying air, V, can be assigned a desired value and held constant. Thus, V, represents the principal design and operating parameter for high-rise, undercage drying systems for poultry manure. For design, it is necessary to restate the predictive relationship (Equation 3.11) in terms of the drying velocity. Combining Equations 3.10 and 3.11 results in the following relationship:

$$M_{sf} = 2271 \left[\left(\frac{AF}{MLF}\right) (V) (P_s - P_a) \right]^{-0.494} \tag{3.12}$$

Solving this equation for the drying air velocity, V, yields the following equation of the form $V = e^x$:

$$V = e^{\left(\frac{\mathrm{In}\left(\frac{M_{sf}}{2271}\right)}{-0.494} - \mathrm{In}\left(\frac{AF}{MLF}\right) - \mathrm{In}\,(P_s - P_a) \right)} \tag{3.13}$$

This equation predicts the required drying air velocity to achieve a desired manurial surface moisture content and is the key process design relationship for high-rise drying systems.

The nature of the variables AF, $P_s - P_a$, and MLF also determine how Equation 3.13 is used in process design. As shown in Figures 3.8 and 3.13, the values of both AF and VPD are at a minimum at the beginning of the manure accumulation cycle. Conversely, MLF is at the maximum value (Table 3.1). Thus, the conditions least favorable for drying occur during the start-up period, and the highest drying air velocities to achieve a specified surface moisture content are necessary.

It appears that the start-up phase of a high-rise drying system is not only the least conducive to moisture removal but also the most critical. If adequate moisture removal does not occur during this period, creation of the conditions which enhance the drying process, such as formation of ridges and development of an optimal environment for biological heat production, is likely to occur. Therefore, the process design of these systems should focus on the initial period of operation where the highest air velocities are required.

In utilizing Equation 3.13 to determine the design drying air velocity for start-up conditions, it is necessary to specify values for AF and VPD that are anticipated during system start-up. It is also necessary to specify a value for manurial surface moisture content for this period. This presents a problem. While it is clear that this value need not approach the desired final system moisture content, it appears that some degree of moisture reduction at the initial phase of system operation is critical to create conditions conducive to subsequent ridge formation and biological heat production. As the system operates, increases in AF and VPD as well as the decrease of the MLF will result in increasingly lower surface moisture contents at the initially selected drying air velocity. The lack of experimental data during high-rise, undercage drying system start-up necessitates specification of a design value for manurial surface moisture content based on judgement and experience. Based upon analysis of results presented by Sobel (15), suggested design values representative of initial conditions are noted in Table 3.6.

TABLE 3.6. SUGGESTED DESIGN VALUES REPRESENTATIVE OF INITIAL CONDITIONS FOR HIGH-RISE DRYING PROCESS DESIGN

Parameter	Design Value
Area factor	1.0
Vapor pressure differential	325 pascals
Manurial surface moisture content	235 percent, dry basis

3.6.3 High-Rise, Undercage Drying Process Design Methodology

The process design of a high-rise, undercage drying system is a simple procedure involving only two design equations (Equation 3.9 and 3.13). The following discussion will outline the necessary steps in determining the required average drying air velocity for this poultry waste management alternative. This will be followed by a design example intended to illustrate the design methodology for these systems and also the effect of bird density by considering two different values for this variable. Finally, the infeasibility of achieving a large moisture reduction in the initial stage of system operation will be illustrated.

The following is a summary of the steps in the process design of a high-rise, undercage drying system for poultry manure:

A. Determine the type of cage system and anticipated number of birds per cage.

B. Determine bird density, birds/m^2, based on cage row width from Table 3.4 or 3.5.

C. Measure moisture production, gm H_2O/bird-day, or estimate a value based on feed metabolizable energy content using Equations 2.1 and 2.3 (Chapter 2).

D. Calculate the moisture loading factor (MLF) using Equation 3.9.

E. Select design values representative of initial conditions for area factor (AF), vapor pressure differential (VPD), and desired manurial surface moisture content (M_{sf}) during the start-up phase of system operation. Values presented in Table 3.6 are suggested.

F. Calculate average drying air velocity using Equation 3.13.

As an illustration of the high-rise, undercage drying design process, the following design example will involve the determination of average drying air velocity for a high-rise system with 30.5 cm x 50.8 cm full stair-step cages. Designs for both 4 and 5 hens per cage will be considered. The birds will receive a diet containing 2800 kcal metabolizable energy (ME)/kg feed. The following is an illustration of the required design steps:

A. Cage system and number of birds per cage has been specified;

B. From Table 3.4, bird densities will be 25.8 m^2/bird and 32.3 m^2/bird for 4 and 5 birds per cage, respectively;

C. Using Equation 2.1, total solids excreted, gm/bird-day = -0.038 (2800 kcal/kg) + 138 = 31.6 gm TS/bird-day;

Then using Equation 2.3,

gm H_2O excreted/bird-day = 3.59 (31.6 gm TS/bird-day) - 26.4 = 87.0 gm H_2O/bird-day.

D. Utilizing Equation 3.9, the moisture loading factor for this situation can be calculated as follows:

MLF = (87.0 gm H_2O/bird-day) x (25.8 birds/m^2) x (1 kg/1000 gm) = 2.24 kg H_2O/m^2-day. For 5 hens per cage, the MLF increases to 2.81 kg H_2O/m^2-day;

E. Using design values for the area factor, vapor pressure differential, and manurial surface moisture content in Table 3.6, the average drying air velocity for the system can then be calculated using Equation 3.13.

$$V = e^{\left[\frac{\ln\left(\frac{235}{2271}\right)}{-0.494} - \ln\left(\frac{1}{2.24}\right) - \ln(325)\right]} = 0.68 \text{ m/sec}$$

For a MLF of 2.81 kg H_2O/m^2-day, the required average drying air velocity increases to 0.85 m/sec.

If this design manurial surface moisture content is reduced to 100 percent, dry basis, the average drying air velocity for a MLF of 2.24 kg H_2O/m^2-day would be 3.83 m/sec. Air velocities of this magnitude are impractical in a high-rise drying system.

3.7 Physical Design Considerations

Presentation of structural design aspects for the high-rise, undercage drying system for poultry wastes is beyond the scope of this manual. Information of this nature is available from other sources such as the Cooperative Extension Service. However, discussion of physical design considerations which have direct bearing on the drying process appear appropriate. Included will be a discussion of:

A. Determination of capacity and location of drying air circulating fans to meet specified design velocities;

B. High-rise versus deep-pit construction;

C. Manure storage area base construction;

D. Bird watering systems.

3.7.1 Determination of Capacity and Location of Circulating Fans

Perhaps the weakest link in the high-rise undercage drying system design process concerns the specification of size and location of the drying air circulating fans in the manure storage area. The basis for determination of necessary capacity for individual fans and the distance between fans is limited. The following consists of best estimates based on limited and incomplete information. Some degree of trial and error should be anticipated.

It is clear that the circulating fans in the manure storage area should be situated to provide a racetrack pattern of air flow (Figure 3.4). This eliminates opposing airstream with resultant dead spots. One problem related to the determination of fan capacity requirements to meet a given design velocity concerns the nature of the airstream. The airstream created by the propeller type fan commonly used in agricultural applications is not uniform. As the data in Table 3.7 illustrates, the air stream changes from a narrow, high velocity to a broader but lower velocity pattern with distance parallel to air flow from the fan. Thus, uniform velocity over the accumulated manure cannot be expected.

TABLE 3.7. CROSS-SECTIONAL VELOCITY DISTRIBUTION FROM HIGH-RISE CIRCULATING FANS* (15)

Distance From Fan Along Air Flow Centerline	Distance Perpendicular to Air Flow Centerline, m	Velocity, m/sec
2.4	0	2.0
	1.1	0.2
	2.1	0.2
13.4	0	0.8
	1.1	0.8
	2.1	0.3

* Each fan had a capacity of 4.7 m^3/sec (10,000 ft^3/min).

The determination of required fan capacity can only be based on average velocity. Fan capacity can be determined on this basis using the following relationship:

$$\text{Required Fan Capacity, } m^3/\text{sec} = (\text{Design Velocity, m/sec})(\text{Cross-Sectional Area, } m^2) \qquad (3.14)$$

With the fans situated to provide a racetrack air flow pattern, the cross-sectional area for each fan will be one-half the cross-sectional area of the manure storage. For example, consider a system with a design velocity of 0.71 m/sec. The manure storage area will have the cross-sectional dimensions of 2.1 m x 12.2 m. Using Equation 3.14, the required capacity for each fan is:

$$\text{Required Fan Capacity, } m^3/\text{sec} = (0.71 \text{ m/sec})(12.8 \text{ m}^2) = 9.1 \text{ m}^3/\text{sec } (19{,}300 \text{ ft}^3/\text{min})$$

The second problem related to circulating fans is the determination of the distance between fans. As shown in Table 3.7, velocity decreases with distance.

Results of measurements of velocity at the airstream centerline with distance from the fan for three fans are presented in Figure 3.21. Each fan had a capacity of 4.7 m^3/sec (10,000 ft^3/min) at zero pascals static pressure. These measurements were obtained after a year of manure accumulation had occurred. Variation is due to the irregular manurial surface (Figure 3.6). In this system, a fan spacing of 35 m (116 ft) was effective in providing an average drying air velocity of 0.4 m/sec (79 ft/min). Unfortunately, similar information for fans of other capacities is totally lacking. A spacing of 30 m (100 ft) is recommended for all fan capacities at this time.

3.7.2 High-Rise Versus Deep-Pit Construction

While this chapter has focused on undercage drying in a high-rise poultry house, the use of this type of system in a deep-pit structure also appears possible. However, two factors lead to a strong recommendation against this approach. First, ventilating fans are normally located at bird level in deep pit houses. Therefore, the frequency of air change and thus removal of moisture laden air in the manure storage area is lessened. This will reduce the vapor pressure differential between the manurial surface and the drying air resulting in a lower evaporation rate.

Second, deep pit construction introduces the potential of water infiltration into the manure storage area. This factor appears to be the principal reason for failure of many deep-pit, undercage drying systems. When conversion of existing deep-pit collection systems to undercage drying is undertaken, waterproofing of the manure storage area is essential.

3.7.3 Manure Storage Area Base Construction

As noted earlier, the base of the manure storage area in the system monitored by Sobel (15) was 15 cm (6 in.) of fine cinders over soil. This approach was used to lower construction costs. To date (1977), this system has been in operation for six laying cycles. Through the third cycle, it was possible to use wheel-type loaders for manure removal. However, deterioration of the base had made the use of track-type equipment mandatory for subsequent clean out operations. Migration of moisture from the manure to the soil was investigated and found to be insignificant (15). However, it is suggested that a material such as concrete be used as a base for the manure storage area to facilitate manure removal.

3.7.4 Bird Watering Systems

A key factor in the successful performance of a well designed high-rise drying system is the prevention of leakage from the bird watering system into the manure storage area. No practical undercage drying system has the evaporation capacity to remove this additional moisture loading. Three types of watering systems are currently in use in the poultry industry. They are nipple valves, cups, and troughs. Experience indicates that in spite of manufacturer's claims, neither nipple valves nor cups will provide a reliable leak-free watering system.

The only alternative is trough watering systems. With proper maintenance, the potential for over-flow is minimal. These systems can be time-clock controlled

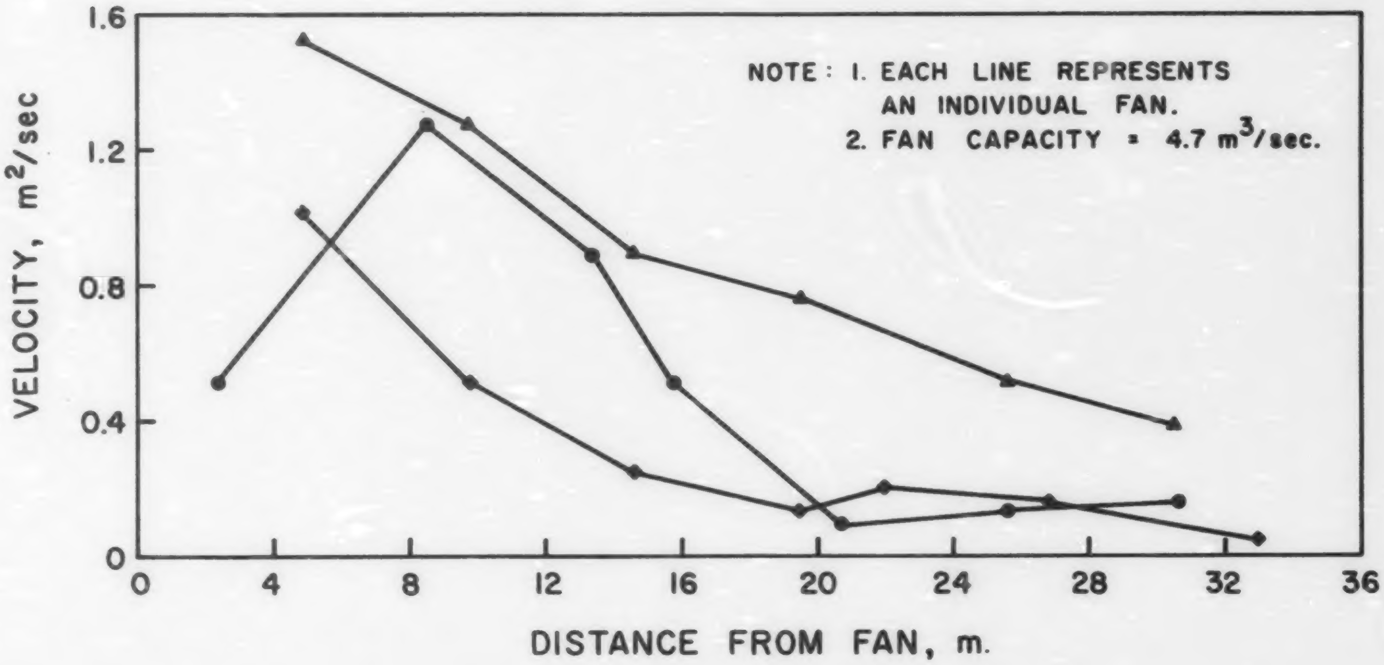

Figure 3.21. Air velocity at the airstream centerline related to distance from fan with accumulated manure (15).

providing water only over selected time periods of the day. This reduces the chance of an overflow going undetected for an extended time period.

3.8 Summary

The overall objective of this chapter has been to present a process design approach for the design of high-rise, undercage drying systems for poultry wastes. The mathematical design relationships presented are empirical and based upon experimental observations. However, the development of these empirical design relationships has been based on concepts fundamental to the drying process. Also included are a discussion of the development and description of high-rise, undercage drying, and illustration of process design methodology, and a brief discussion of physical design considerations.

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CHAPTER 4

AEROBIC BIOLOGICAL STABILIZATION OF POULTRY MANURE

4.1 Introduction

Research (1, 2, 3, 4) has demonstrated that aerobic biological treatment processes can provide a feasible alternative for the management of poultry wastes and provide the following advantages:

A. Reduction or elimination of offensive odors;

B. An innocuous method for nitrogen removal when required;

C. Waste stabilization through the removal of readily biodegradable organic compounds;

D. Elimination of breeding conditions for flies and sites which will harbor rodents.

Aerobic biological treatment processes can be divided into two categories, fixed film and slurry type processes. The trickling filter and rotating biological contactor (RBC) are examples of units employing the fixed film process. Diffused aeration and the oxidation ditch are illustrations of systems employing the slurry type process.

Both trickling filters and RBC's are designed to aerobically treat dilute wastes having low concentrations of particulate solids. High particulate solids concentrations result in clogging of trickling filters thus reducing performance. With RBC's, particulate solids will accumulate in disc wet wells reducing the hydraulic retention time (HRT) and can produce septic conditions. The use of the fixed film process for the stabilization of animal wastes including poultry manure requires liquid-solid separation prior to biological treatment. This requires an additional unit process and creates an additional unstabilized waste stream.

The use of slurry type processes for poultry and other animal manures is attractive due to the ability to receive wastes with high concentrations of particulate solids, thus eliminating pretreatment. Both diffused aeration and the oxidation ditch are slurry type processes that have been evaluated to determine their potential as undercage systems for the stabilization of poultry wastes (1, 2, 3). In a pilot plant scale evaluation of undercage diffused aeration, it was reported that airflow rates capable of meeting biological oxygen requirements were inadequate to maintain completely mixed conditions (3). Sizable accumulations of settled solids and diffuser plugging were major problems based upon design recommendations (5). For adequate mixing in aeration tanks, aeration requirements for adequate mixing should be five times that for oxygen transfer with these wastes.

At present (1977), the oxidation ditch appears to be the most feasible system for the aerobic biological stabilization of poultry manure. Therefore, this discussion will focus on the oxidation ditch. However, it should be recognized that many of the fundamental concepts and process design relationships discussed in relation to the oxidation ditch are equally applicable to other slurry type waste treatment systems.

4.2 Objectives

The objectives of this chapter are to:

A. Discuss the development of the oxidation ditch;

B. Discuss the theoretical concepts germane to aerobic biological waste stabilization;

C. Describe the experimental basis for and present a rational process design approach for oxidation ditch aeration of poultry wastes;

D. Present process design examples;

E. Discuss physical design considerations.

4.3 The Oxidation Ditch

The oxidation ditch, also known as the Pasveer ditch, was developed at the Institute of Public Health Engineering in the Netherlands as a low cost treatment system for wastewater from small communities and industries (6). The oxidation ditch consists of a circular or racetrack shaped circuit or ditch (Figure 4.1) and an aeration unit. Brush or cage type surface aerators are used extensively in oxidation ditches (Figures 4.2 and 4.3). These aerators consist of horizontal revolving shafts with attached blades extending below the mixed liquor surface. Conventional oxidation ditch aerators serve two functions; oxygen transfer and mixing.

The oxidation ditch as originally developed was designed to receive unsettled domestic and/or industrial wastewater and provide treatment as well as sludge digestion. Employing discontinuous aerator operation, secondary clarification prior to effluent discharge can be achieved in the ditch. Thus, primary and secondary clarifiers as well as sludge digestion facilities are not required.

The oxidation ditch is an attractive biological treatment system for livestock wastes due to its ability to handle wastes with high concentrations of particulate solids. In 1967, it was estimated that about 400 oxidation ditches were in operation in agricultural applications in the United States (7). Most of these systems are used for swine wastes but the oxidation ditch also has been utilized for dairy, beef, and poultry wastes.

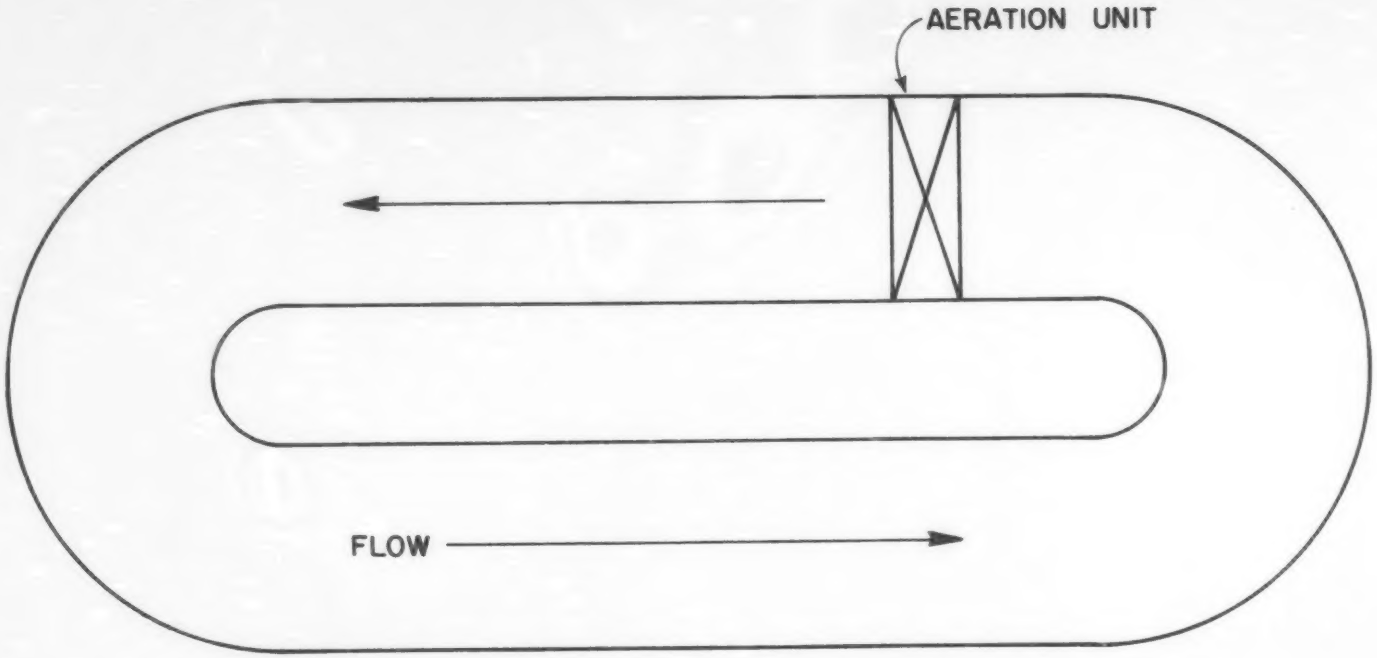
AERATION UNIT
FLOW

Figure 4.1. Diagram of the basic oxidation ditch.

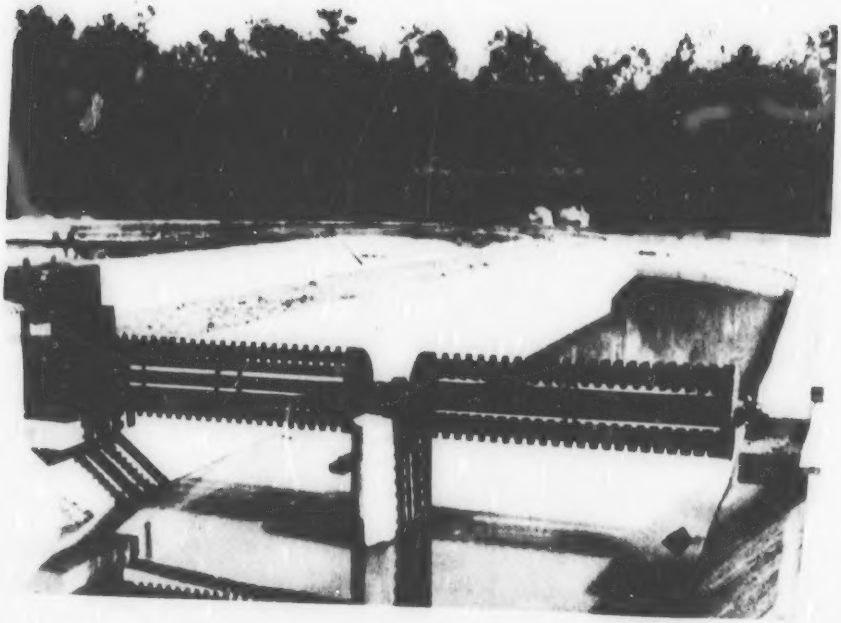

Figure 4.2. A brush type surface aerator.

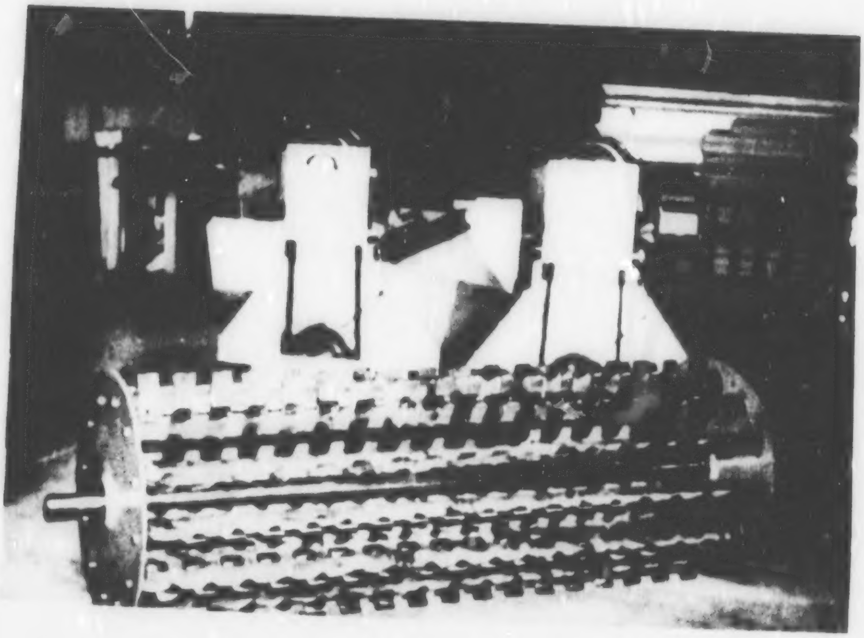

Figure 4.3. A cage type surface aerator.

In addition to odor control, the oxidation ditch offers the following advantages as compared to other biological treatment processes:

A. Low capital costs;

B. Requires little attention and maintenance;

C. Once operating properly, has the ability to handle shock loads;

D. Ease of incorporation into production facilities.

Figure 4.4 is a vertical cross-section of an undercage oxidation ditch for laying hens.

4.4 Theoretical Concepts

The biological stabilization of poultry wastes is a microbial process involving transformations of carbonaceous and nitrogenous compounds. Knowledge of basic microbial concepts and transformations provide a basis for the development of a rational design approach delineating system performance and aeration requirements. It is the objective of this section to present a brief review of basic microbial relationships and to describe transformations of carbonaceous and nitrogenous compounds and the resulting oxygen requirements. This is followed by a discussion of various substrate removal relationships and oxygen transfer.

4.4.1 General Microbial Concepts

The general biochemical relationship that describes any biological waste treatment process is:

$$\text{Energy containing metabolizable wastes} + \text{microorganisms} \rightarrow \text{end products} + \text{more microorganisms} \qquad (4.1)$$

Only part of the substrate is converted to end products. End products are the result of biochemical reactions which provide energy for cell maintenance and microbial synthesis. The remaining substrate is transformed into new cell mass.

The organic matter initially converted to cellular material can be transformed subsequently to end products via two mechanisms. One is death of the organisms which occurs in all biological systems. Following death, cells lyse and the released organic matter is available as substrate for the remaining microorganisms. The other occurs when substrate in the system becomes limiting. Organisms can metabolize the storage components of their own protoplasm to acquire energy. This process is termed endogenous respiration. The results of both mechanisms can be described as:

$$\text{Microorganisms} \rightarrow \text{end products} + \text{fewer microorganisms} \qquad (4.2)$$

The portion of the cellular material metabolized following death and/or via endogenous respiration is a function of the mean time that the waste has been

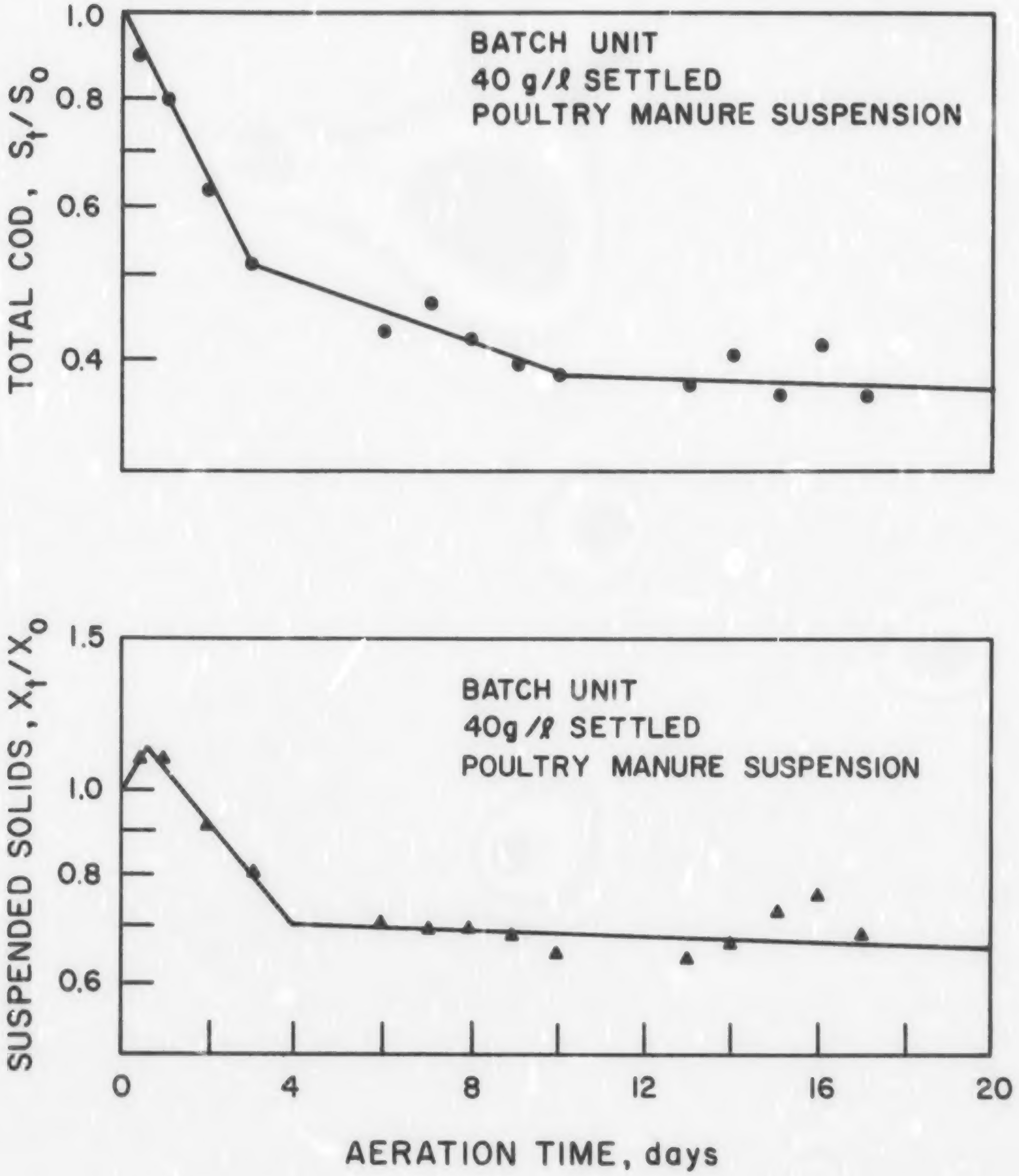

Figure 4.4. Removal characteristics of total COD and suspended solids - semi-logarithmic plot (13).

subject to treatment. As time of treatment increases, the portion of the waste transformed to end products increases, and the net yield of cellular mass decreases.

As described, microorganisms utilize a portion of the available substrate for the synthesis of new cell mass. Mathematically microbial growth can be described as:

$$\frac{dX}{dt} = \mu X \tag{4.3}$$

where: X = microorganism concentration, mass/volume

t = time

μ = net specific growth rate, mass/mass-time or time^{-1}

$\frac{dX}{dt}$ = growth rate of microorganisms, mass/volume-time

The net specific growth rate is a function of substrate availability. If substrate is not limited, microbial growth should occur at an exponential rate. This is not typical of biological waste treatment systems. Normally, microbial growth is substrate limited.

Under growth limiting conditions, the net specific growth rate is not constant but is a function of the limiting substrate concentration. Monod (8) and others have utilized the following equation to describe the interaction between the net specific growth rate and the concentration of the growth limiting substrate.

$$\mu = \frac{\hat{\mu} S}{k_s + S} \tag{4.4}$$

where: $\hat{\mu}$ = maximum net specific growth rate at infinite substrate concentration, time^{-1}

S = growth limiting substrate concentration, mass/volume

k_s = a velocity constant equal to the substrate concentration at one-half the maximum net specific growth rate, mass/volume

The half velocity constant, k_s, is a characteristic of the microorganisms and the given substrate. For agricultural wastes such as poultry manure, organic carbon should be the growth limiting substrate for heterotrophic microorganisms.

4.4.2 Microbial Transformations of Carbon and Nitrogen - Oxygen Requirements

The carbon and nitrogen transformations represent sources of oxygen utilization in the stabilization process. Equation 4.5 is a simplified presentation of the aerobic conversion of organic carbon to cell mass, $C_5H_7O_2N$, and carbon dioxide.

$$\text{Organic carbon} + O_2 \xrightarrow[\text{microorganisms}]{\text{heterotrophic}} C_5H_7O_2N + CO_2 \qquad (4.5)$$

The compounds in poultry manure containing nitrogen, such as proteins and uric acid, also are metabolized by the heterotrophic microorganisms. This process, termed ammonification, can be expressed as:

$$\text{Organic nitrogen} \xrightarrow{\text{ammonification}} NH_3 + H_2O \rightleftarrows NH_4^+ = OH^- \qquad (4.6)$$

While nitrogen is an important nutrient in any biological system, the nitrogen content of poultry manure exceeds the microbial requirements. Thus in the absence of nitrification, a residual ammonia concentration will occur. Ammonification results in an increase in pH due to ionization of NH_4OH (Equation 4.6). If ammonium concentrations and pH are sufficiently high, ammonia volatilization will occur.

Under aerobic conditions, ammonia nitrogen can be microbially oxidized to nitrite and nitrate-nitrogen. Two groups of autotrophic microorganisms are primarily responsible for this transformation. They are *Nitrosomonas* and *Nitrobacter*. The oxidation of NH_4^+ to NO_3^- is a two step process termed nitrification and can be expressed as follows:

$$NH_4^+ + 3/2\ O_2 \xrightarrow{\text{Nitrosomonas}} NO_2^- + 2H^+ + H_2O \qquad (4.7)$$

$$NO_2^- + 1/2\ O_2 \xrightarrow{\text{Nitrobacter}} NO_3^- \qquad (4.8)$$

The production of hydrogen ions (Equation 4.7) results in a decrease in pH.

A key factor in the design of aerobic waste stabilization systems such as the oxidation ditch is the determination of exerted oxygen demand. Due to the large variety of compounds containing organic carbon and the differences in biodegradability between these compounds, it is not possible to use stoichiometric relationships to predict carbonaceous oxygen demand. However, both biochemical oxygen demand (BOD) and chemical oxygen demand (COD) tests provide an indirect measure of available substrate in terms of the oxygen equivalent of organic matter. An advantage of the BOD determination is that unlike the

COD test, it includes only organic matter susceptible to biological degradation. However, the BOD test is dependent on both the time period and initial microbial population. It may or may not include nitrogenous oxygen demand (NOD) depending on the presence or absence of nitrifying microorganisms. This presents difficulties in comparing the results from raw and treated waste samples.

The COD test is an alternative. Although this approach includes organic matter not susceptible to biological degradation, it does not include the NOD of ammonia nitrogen. If nitrites are present, they will be chemically oxidized to nitrates. Correction for this factor is simple requiring only concurrent determination of the nitrite concentration in the sample.

Neither test is ideal but in a situation where change through a treatment system is being measured, COD appears to have an advantage. By assuming that a change in COD is due completely to biodegradation, a gm of BOD is satisfied when organic matter equivalent to a gm of COD is biologically oxidized. This assumes that there are no reduced compounds to exert an immediate oxygen demand in terms of simple chemical oxidation. Therefore, definition of COD removal relationships can be utilized to determine exerted carbonaceous oxygen demand and aeration requirements.

For the nitrogenous oxygen demand (NOD), more precise stoichiometric relationships (Equations 4.7 and 4.8) are available. Theoretically, 4.57 gm of oxygen are required to oxidize one gm of ammonia nitrogen to nitrate nitrogen. It should be recognized that NOD is a function of the ammonification process. Thus, knowledge of the rate of degradation of organic nitrogen is important to determination of NOD.

The following general equation describes the rate of oxygen utilization for the oxidation of carbonaceous matter:

$$\frac{dO}{dt} = a\left[\frac{dF}{dt}\right] + b\ c\ X \qquad (4.9)$$

where $\frac{dO}{dt}$ = rate of oxygen utilization

$\frac{dF}{dt}$ = rate of substrate utilization

a = coefficient to convert substrate units to oxygen units

b = microbial decay coefficient

c = coefficient to convert cell mass to oxygen units

X = microorganism concentration

Since both substrate utilization and endogenous respiration are manifested as COD removed, Equation 4.9 can be rewritten as:

$$\frac{dO}{dt} = \frac{d(COD)}{dt} \tag{4.10}$$

with the inclusion of nitrogenous oxygen demand, Equation 4.10 must be modified as follows:

$$\frac{dO}{dt} = \frac{d(COD)}{dt} + 3.43\,\frac{d(NH_4\text{-}N)}{dt} + 1.14\,\frac{d(NO_2\text{-}N)}{dt} \tag{4.11}$$

where: $\frac{d(NH_4\text{-}N)}{dt}$ and $d(NO_2\text{-}N)$ are respectively, the rates of oxidation of ammonia to nitrite and nitrite to nitrate.

Thus oxygen demand for various degrees of waste stabilization can be predicted.

4.4.3 Substrate Removal Relationships

While an understanding of the microbial transformations which result in waste stabilization is important, the identification of the relationships between system performance and operating parameters is equally necessary for rational design. This not only permits satisfaction of specific treatment objectives but also allows determination of oxygen requirements (Equations 4.10 and 4.11). The objective of this section is to briefly review several approaches to describe substrate removal relationships.

Perhaps the earliest rational approach to slurry type biological treatment design was developed from the observation that effluent quality was related to the ratio of substrate loading (F) per unit time and the mass of microorganisms (M). As the substrate loading increased, effluent quality deteriorated. Based upon these observations, the food to microorganisms (F/M) ratio was established as a design parameter for biological treatment processes (9). Owens, et al. (10) have investigated the effects of different F/M ratios on effluent quality in the aerobic treatment of swine wastes. Their observations of decreasing effluent quality at increasing F/M ratios concurred with results of previous studies.

Although the F/M concept is fundamentally sound, it is difficult to use due to problems in determining concentrations of active microorganisms. Traditionally, volatile suspended solids (VSS) have been used to estimate active mass. Due to high concentrations of VSS present in animal wastes such as poultry manure, this method of estimation has little significance in these wastewaters.

Further attempts to improve the state of the art regarding design of slurry type biological waste treatment systems have resulted in the development of mathematical models by several investigators. These models utilize one of two microbial kinetic relationships, first order substrate utilization or substrate limited growth.

The first order substrate utilization approach describes the rate of removal of biologically available organic materials (substrate) as a first order reaction. This description of microbial kinetics has been utilized by McKinney (11), Goodman and Englande (12) and others as the basis for mathematical biological waste treatment models. Prakasam, et al. (13) reported that removal of chemical oxygen demand in poultry wastewaters can be described as a first order reaction.

An alternative is to describe microbial growth in waste treatment systems as substrate limited (Section 4.4.1). Substrate limited growth appears a more representative description of conditions in biological waste treatment systems than first order substrate utilization. The concept of substrate limited growth provides the basis for the treatment model presented by Lawrence and McCarty (14). In this model, the concept of biological solids retention time, θ_c, has been proposed as a unifying design parameter for slurry type biological waste treatment systems in that all system variables can be related to θ_c. Mathematically, θ_c can be represented as:

$$\theta_c = \frac{X_T}{\left[\frac{\Delta X}{\Delta t}\right]_T} \qquad (4.12)$$

where: X_T = total active microbial mass in the treatment system, mass

$\left[\frac{\Delta X}{\Delta t}\right]$ = total quantity of active microbial mass leaving the system in a unit of time, mass per time.

As θ_c increases, the effluent concentration of the growth limiting substrate will decrease.

The microorganism concentration is a function of the available substrate concentration and θ_c. As θ_c increases, the microorganism concentration will decrease due to endogenous respiration.

The concept of biological solids retention time is not unlike the food to microorganism (F/M) approach to design slurry type biological systems. When a value for the microorganism concentration is specified in the F/M approach, a value for θ_c is specified implicitly but not explicitly. The F/M and θ_c design approaches have been compared in a treatability study of an oil refinery wastewater (15) and found to produce similar designs.

Determination of θ_c as defined in Equation 4.12 requires measurement of active biomass. However, assuming complete mixing resulting in the uniform distribution of microorganisms, the solids retention time (SRT) of the solids can be used to estimate θ_c. SRT is the theoretical time that solids are retained in the treatment system and can be expressed as:

$$\text{SRT} = \frac{\text{wt of solids in the system}}{\text{wt of solids leaving the system/time}} \qquad (4.13)$$

θ_c is a function of the active biomass in a system while SRT can be determined by measuring other forms of solids such as volatile, fixed, or total solids. If the system is completely mixed, SRT is a reasonable estimate of θ_c and is the key factor in the utilization of this approach. The unifying parameter, SRT, can be estimated by utilizing an easily determined parameter, solids concentration.

4.4.4 Oxygen Transfer

In the microbial transformations described in Equations 4.5, 4.7, and 4.8, oxygen is shown as a reactant. In these microbial mediated reactions, molecular oxygen serves as the terminal electron acceptor in the oxidation processes. The utilization of oxygen as the terminal electron acceptor is the factor which differentiates between aerobic and anaerobic biological processes. Earlier sections have been concerned with the identification of sources and delineation of the magnitude of microbial oxygen demand. This section deals with the subject of oxygen transfer.

Oxygen is only slightly soluble in water. The rate of oxygen going into solution is proportional to the differential between the saturated and equilibrium concentrations. The rate of oxygen transfer can be expressed as:

$$\frac{dC}{dt} = K_L a(C_s - C_L) \qquad (4.14)$$

where: $\frac{dC}{dt}$ = rate of change of dissolved oxygen concentration with time, mass/volume-time

$K_L a$ = overall gas transfer coefficient, time^{-1}

C_s = oxygen saturation concentration for a given liquid temperature, atmospheric composition and pressure, mass/volume

C_L = actual oxygen concentration at time t, mass/volume

To maintain aerobic conditions, the rate of oxygen transfer should equal or exceed the biological oxygen requirements of the system. The rate of oxygen transfer under process conditions can be described as:

$$N = \alpha K_L a \ (\beta C_s - C_L)(V) \qquad (4.15)$$

where: N = oxygenation capacity, mass O_2/time

α = the ratio of $K_L a$ in wastewater to $K_L a$ in tapwater, dimensionless

β = the ratio of C_s in wastewater to C_s in tapwater dimensionless

V = volume of water under aeration, volume.

The values of K_La and V are functions of the aeration unit and system volume, and are constant for a given operating condition. C_s is an independent variable which is related to liquid temperature and atmospheric pressure. Both α and β are dependent variables. C_L is a function of the relationship between the quantity of oxygen supplied and demand. Both α, β and C_L directly affect the quantity of oxygen transferred under process conditions.

Although α is a function of many factors, α and β are primarily related to mixed liquor characteristics (16). Small quantities of surface active agents can cause significant reductions in α values (17-19). Downing (18) found that suspended solids in the range of 1,000 to 6,000 mg/ℓ had little effect on oxygen transfer. However, α was reported to be reduced to 0.2 in a sludge with a total solids concentration of 10,000 mg/ℓ (20).

The value of C_L under operating conditions is important in that as the rate of oxygen transfer, N, increases above that necessary to meet the microbial oxygen demand, C_L will increase. This will result in a decreased oxygen deficit which represents the driving force for oxygen transfer. This in turn will reduce the oxygen transfer efficiency of the aerator and increase operating costs. In any aeration system, minimal, $\leq$ 2 mg/ℓ, dissolved oxygen concentrations (C_L) are adequate.

4.5 Process Design Relationships

The design criteria for aerobic treatment of animal wastes suggested by Jones, et al., (21) have served as the standard basis of design for these systems. Both the Midwest Plan Service (22) and Agriculture Canada (23) suggest this method of design for oxidation ditches. These design criteria are empirical based upon studies involving swine and dairy cattle wastes. System volume is determined using the organic loading rate concept. The recommended loading rate is 0.5 kg BOD_5/m^3/day (0.03 lb BOD_5/ft^3/day). The suggested parameter for oxygen requirement is twice the daily BOD_5 loading assuming that oxygen transfer under process conditions will be 80 percent of tapwater values.

Although many systems developed from these empirical parameters have performed satisfactorily, this approach has several disadvantages. It is difficult to extrapolate between different wastes and environmental conditions. Reasons for process failures are unclear since the design and operation of the system is not based on process fundamentals. Possibly the greatest liability of the empirical approach is its inflexibility. No opportunity exists to adjust the degree of waste stabilization to specific requirements. This is especially significant when only a minimal degree of stabilization is required.

During the past 7 years, laboratory, pilot plant, and full scale investigations of aerobic stabilization of poultry wastes have been conducted by personnel of the Agricultural Waste Management Program, Cornell University. A common objective of these studies has been the development of rational design parameters for these systems. It is the objective of this section to present and integrate the results of these studies into a rational design approach. This will include discussion of poultry manure as a microbial substrate, substrate removal relationships and oxygen transfer under process conditions.

4.5.1 Poultry Manure as a Microbial Substrate

Biological stabilization of poultry manure results from its utilization as microbial substrate. Fresh poultry excreta contains soluble and particulate organic and inorganic compounds. The inorganic fraction, fixed solids, contains phosphorus, calcium, and chlorides as major components (24). This is an expected result since both calcium and phosphorus are fed at levels in excess of the birds physiological needs to insure adequate uptake. Reported values indicate that the fixed solids fraction can range between 23 and 33 percent of total solids (Table 2.4).

The organic fraction of these wastes is comprised of both carbonaceous and nitrogenous compounds. Organic carbon is present as carbohydrates, lipids, and proteins. The nitrogen in freshly excreted material is almost totally in the organic form being present as both proteins and uric acid. Between 65 and 75 percent of the nitrogen is in the form of uric acid (25).

Several parameters are used to characterize poultry manure and to assess performance of biological waste treatment processes. These include total solids (TS), volatile solids (VS), chemical oxygen demand (COD) and organic nitrogen (ON). Each of these parameters involves the measurement of organic matter.

Due to the complex nature of the organic fraction of poultry manure, substrate utilization rates for various components and therefore, biodegradability vary significantly. In a batch study involving the non-settleable components of a poultry manure suspension, three distinct COD removal rates were observed (Figure 4.4). The most rapid removal of COD occurred during the first 10 days of treatment. Additional removal resulted from utilization of more slowly biodegradable compounds. Degradation of soluble organic matter appears more rapid than that of particulate material. The removal of suspended solids followed a similar pattern, although two rather than three removal rates were observed (Figure 4.4).

The results of long term aeration studies (Table 4.1) indicate that a substantial portion of the organic fraction of poultry manure is either not or very slowly biodegradable. This material represents the refractory organic fraction of these wastes. The term refractory fraction refers to that portion of the waste which is resistant to biological degradation and remains undegraded at the time when the rate of degradation has decreased to a level as to be insignificant from an engineering standpoint (27).

Therefore, each parameter used to describe poultry manure which includes the organic fraction can be subdivided into biodegradable and refractory fractions as follows:

$$S_o = (S_b)_o + S_r \qquad (4.16)$$

TABLE 4.1. OBSERVED REMOVAL OF TOTAL SOLIDS, VOLATILE SOLIDS, AND CHEMICAL OXYGEN DEMAND IN LONG TERM AERATION STUDIES

Parameter	Percent Removal		
Solids Retention Time	4.5 Months (1)*	6.5 Months (26)	7.5 Months (26)
Total Solids	53	43	42
Volatile Solids	63	56	54
COD	63	60	--

*Numbers in parenthesis indicate data source.

where: S_o = the concentration of any organic parameter in the waste, mass/volume or mass/mass

$(S_b)_o$ = the biodegradable fraction

S_r = the refractory fraction

The refractory fraction can be expressed as:

$$S_r = R(S_o) \tag{4.17}$$

where: R = the ratio of the refractory to the total concentration of any organic parameter, expressed as a decimal.

Since the refractory fraction as defined is unaffected by biological processes, it will be present in the effluent (S_1) from biological waste stabilization systems.

$$S_1 = (S_b)_1 + S_r \tag{4.18}$$

where: $(S_b)_1$ = the unstabilized biodegradable fraction of the effluent

The refractory ratio (R) can be determined by plotting S_1/S_o versus $(S_o \cdot SRT)^{-1}$ (Figure 4.5). Based on the assumption that as the solids retention time (SRT) approaches infinity, the biodegradable fraction of the influent also approaches zero. Therefore, the intercept on the ordinate axis represents the refractory fraction (R) of S_o. This procedure for the determination of R has been presented previously (28, 29, 30).

Knowledge of the magnitudes of the biodegradable and refractory fractions of poultry manure is important in that it identifies the practical upper limits of biological stabilization. The refractory fractions of total solids, volatile solids, chemical oxygen demand, and organic nitrogen were determined using data reported by Martin and Loehr (2). These data are presented in the Appendix, Table A-1. The refractory fractions of each parameter were determined graphically (Figures 4.6 to 4.9). Linear regression analysis was utilized to determine the value of R, the intercept of the ordinate axis. These results are summarized in Table 4.2.

4.5.2 Substrate Removal Relationships for Poultry Wastes

Definition of substrate removal relationships are necessary for the rational design and operation of aeration systems for poultry wastes. The relationships of interest involve the removal of both volatile solids (VS) and total solids (TS), chemical oxygen demand (COD), and organic nitrogen (ON) as well as nitrification in certain situations. The removal of both chemical oxygen

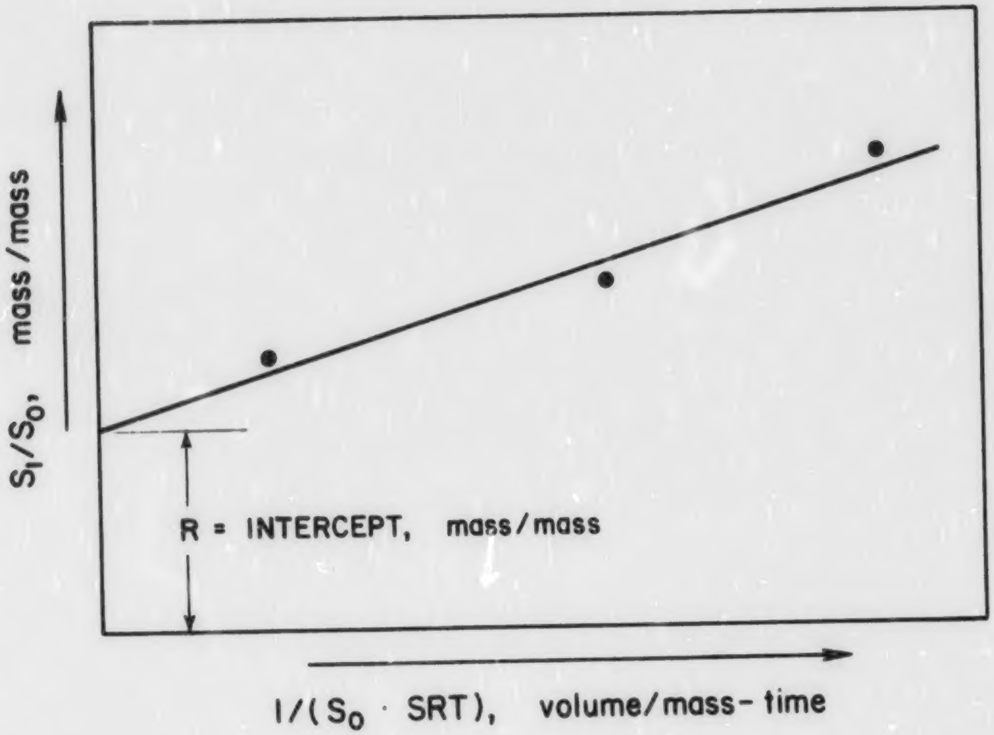

Figure 4.5. Graphical plot to determine the refractory fraction of a partially biodegradable material.

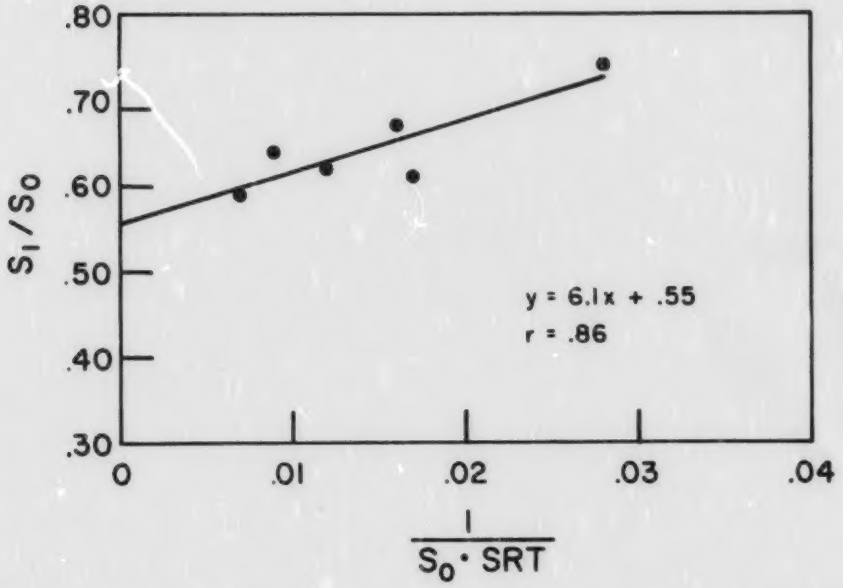

Figure 4.6. Graphical plot to determine refractory fraction of poultry manure total solids.

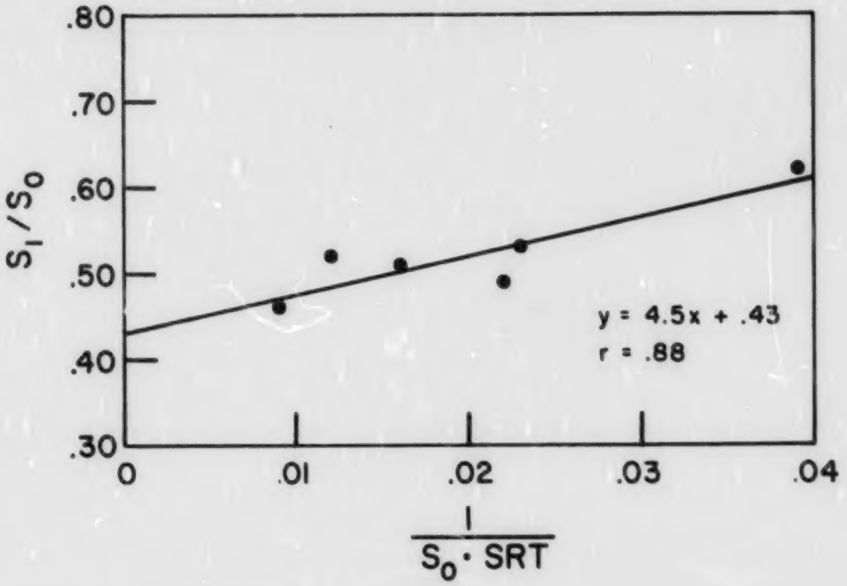

Figure 4.7. Graphical plot to determine refractory fraction of poultry manure volatile solids.

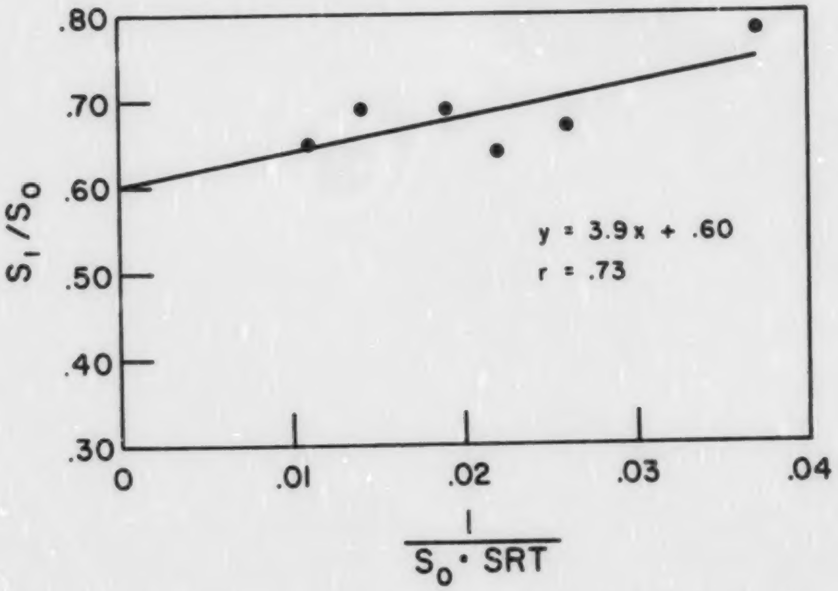

Figure 4.8. Graphical plot to determine refractory fraction of poultry manure COD.

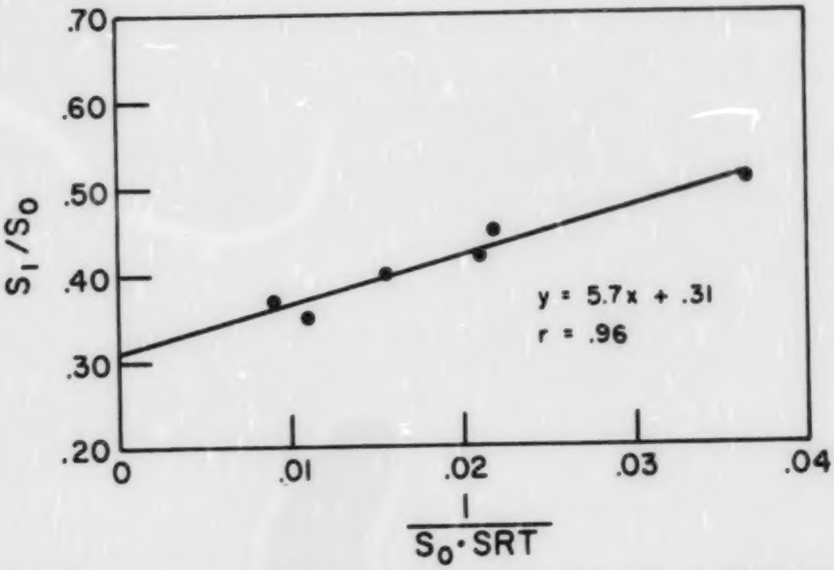

Figure 4.9. General plot tc determine refractory fraction of poultry manure organic nitrogen.

TABLE 4.2. REFRACTORY AND BIODEGRADABLE FRACTIONS OF POULTRY MANURE

Parameter	Refractory Fraction, R	Biodegradable Fraction, B
Total Solids	0.55	0.45
Volatile Solids	0.43	0.57
Chemical Oxygen Demand	0.60	0.40
Organic Nitrogen	0.31	0.69

demand and organic nitrogen are important not only in terms of effluent characteristics but also in the determination of aeration requirements.

Analysis of mass balance results (2, 31) from two full scale evaluations of aeration systems for poultry wastes has indicated that biological destruction of TS, VS, COD, and ON can be described as a function of solids retention time (SRT). Using individual and combined results from these two studies, the development of both first order substrate utilization and substrate limited growth kinetic relationships using SRT as the controlling process parameter was attempted.

Neither the first order substrate utilization nor the substrate limited growth models provided predicted values that were in good agreement with observed results. A possible explanation is that more than one removal rate exists for each parameter due to the complex nature of the waste. Phasic removal patterns have been reported for COD and suspended solids (Figure 4.4)(13).

The alternative was the development of empirical relationships between SRT and removal for each parameter. From the analysis of available mass balance results (2), it was found that for SRT values between 10 and 36 days, a linear relationship provided a reasonable approximation of these relationships. These linear relationships can be expressed in the general form:

$$\text{Removal, \%} = A(\text{SRT}) + B \qquad (4.19)$$

Linear regression analysis was used to determine values of the coefficients A and B for each parameter. These results are presented in Figures 4.10 through 4.13 and in the following equations:

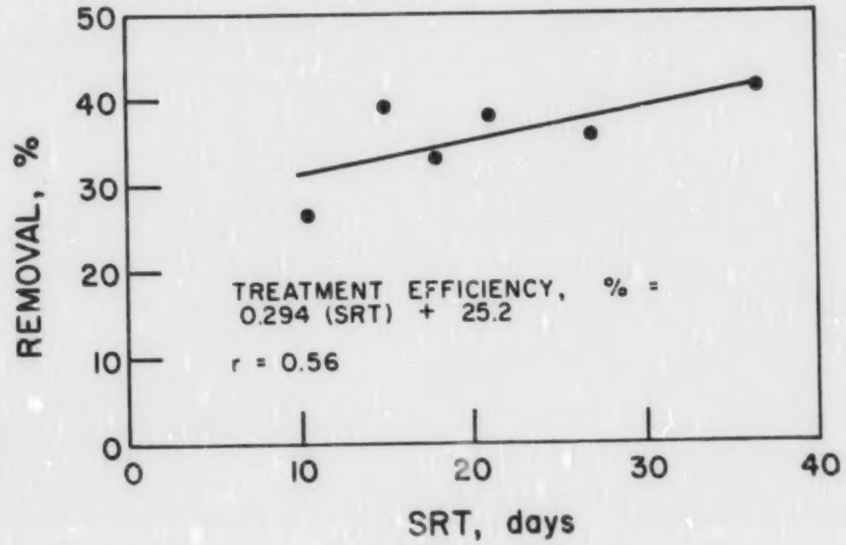

Figure 4.10. Observed relationship between SRT and removal of total solids.

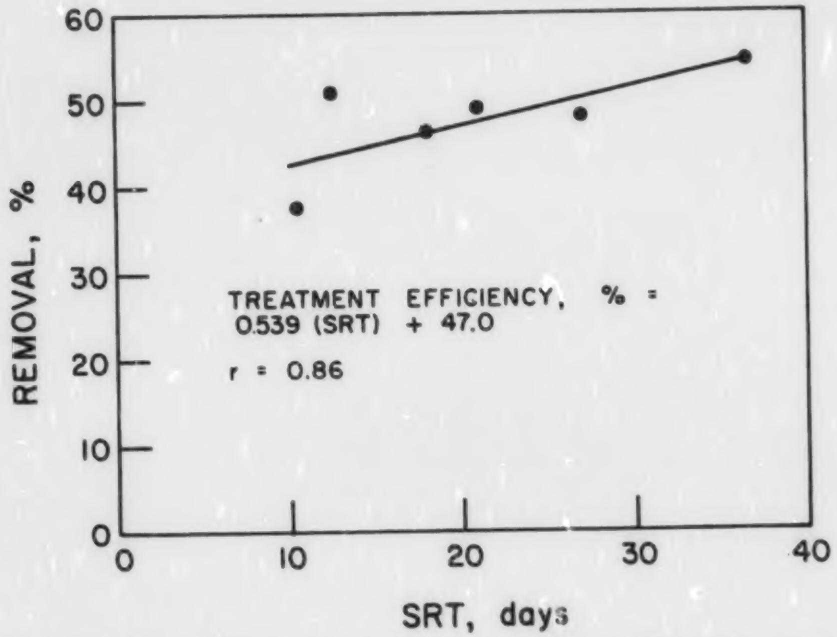

Figure 4.11. Observed relationship between SRT and removal of volatile solids.

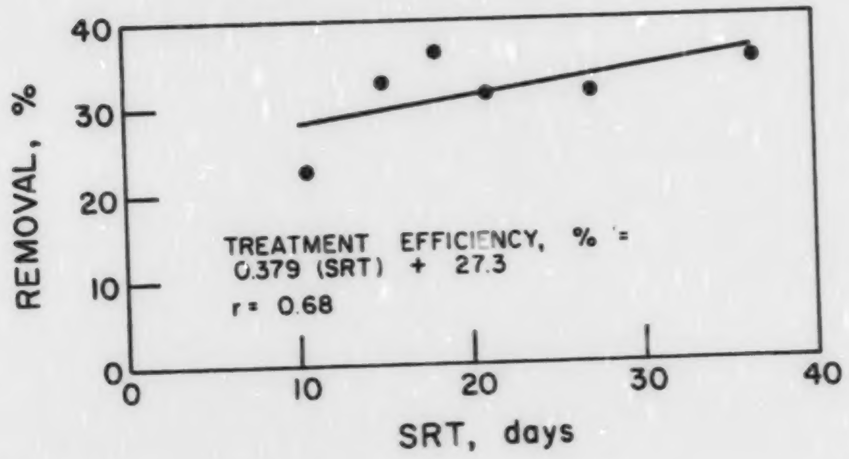

Figure 4.12. Observed relationship between SRT and removal of COD.

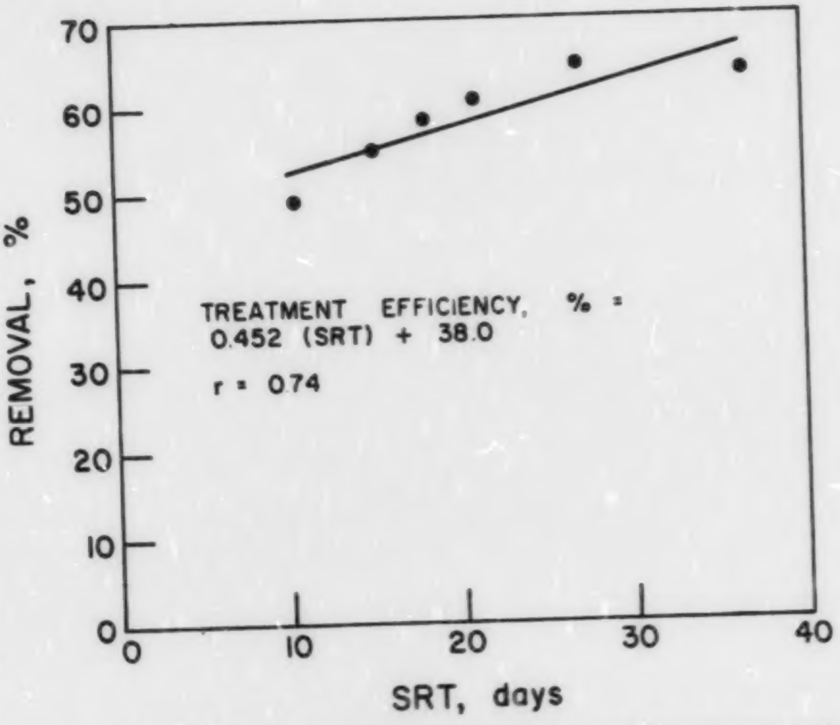

Figure 4.13. Observed relationship between SRT and removal of organic nitrogen.

$$\text{Removal of Total Solids, \%} = 0.379\ (\text{SRT}) + 27.3 \qquad (4.20)$$

$$\text{Removal of Volatile Solids, \%} = 0.452\ (\text{SRT}) + 38.0 \qquad (4.21)$$

$$\text{Removal of COD, \%} = 0.294\ (\text{SRT}) + 25.2 \qquad (4.22)$$

$$\text{Removal of Organic Nitrogen, \%} = 0.539\ (\text{SRT}) + 47.0 \qquad (4.23)$$

These four equations provide the basis for a process design approach which with information on the raw waste characteristics and a SRT predicts both carbonaceous and nitrogenous oxygen demand as well as effluent characteristics. These equations also can be used to determine the required SRT to obtain a specific effluent characteristic and to quantify other characteristics. While not entirely satisfactory from a theoretical standpoint, these linear relationships in combination with delineation of the practical limits of biodegradability appear to provide practical design tools for these systems. However, it should be recognized that the validity of Equations 4.20 through 4.23 is limited to SRT values between 10 and 36 days.

Nitrification is not a necessary prerequisite for the successful operation of aeration systems for poultry wastes. It has been demonstrated that odor control, stabilization of carbonaceous compounds, and nitrogen removal can be achieved in the absence of nitrifying processes (2). The method of nitrogen removal was ammonia stripping. Unless limited by available dissolved oxygen, nitrification can be expected to occur to some degree in any aeration system. Intentional introduction of nitrifying organisms into these systems is not necessary.

While not a requirement as part of the aerobic waste stabilization process, nitrification may be desirable in certain situations for the control of the odor of ammonia and/or other reasons. In these instances, knowledge of the kinetic relationships describing the two steps of the nitrification process is necessary. Both Nitrosomonas and Nitrobacter have lower growth rates as compared to heterotrophic microorganisms which utilize carbonaceous compounds. Therefore, in situations where nitrification is desired, the selection of a design value for the SRT should be based on the growth kinetics for nitrifying organisms.

The substrate limited growth relationship has been used to describe the nitrification process. Based upon this kinetic relationship, the minimum biological solids retention time (θ_c^m) necessary to maintain process stability has been defined as (14):

$$\theta_c^m = (Yk - b)^{-1} \qquad (4.24)$$

where: Y = growth yield coefficient, mass/mass

k = maximum rate of substrate utilization per unit weight of microorganisms, time^{-1}

b = microorganism decay coefficient, time^{-1}

Values for kinetic coefficients for both ammonia and nitrite oxidation as well as calculated values for θ_c^m at 20°C are presented in Table 4.3.

TABLE 4.3. KINETIC COEFFICIENTS FOR BIOLOGICAL NITRIFICATION (32)

Process	Y, mg/mg N	b, days^{-1}	k, mg N/mg-day	θ_c^m, days at 20°C
NH_4-N Oxidation	0.29	0.05	1.8	2.1
NO_2-N Oxidation	0.084	0.05	4.7	2.9

The θ_c^m values of 2.1 and 2.9 days for ammonia and nitrite oxidation at 20°C compare favorably with the observed value for θ_c^m of 2 days for nitrification in aerated poultry wastes (33).

Where system temperatures of less than 20°C are anticipated, θ_c^m values will be greater than those at 20°C. Specific values can be calculated by first correcting the maximum rate of substrate utilization coefficient, k, for change in temperature and then using Equation 4.24. A modified form of the van't Hoff - Arrhenius relationship, Equation 4.25, will provide a reasonable estimate of the effect of temperature on k.

$$k_{T_2} = k_{T_1} \cdot \theta^{(T_2 - T_1)} \qquad (4.25)$$

where: θ = 1.106

T = temperature, °K

The value of 1.106 is that reported for nitrification in the temperature range of 5-20°C (34).

The substrate removal relationships (Equations 4.20 through 4.23) provide the basis for a process design approach for poultry waste aeration systems where SRT is an independent design and operating parameter. However, in situations where nitrification is a design objective, minimum design SRT values may be limited by the values of θ_c^m necessary to maintain nitrification process stability.

4.5.3 Oxygen Transfer

As previously discussed, α and β (Equation 4.15) under process conditions are functions of mixed liquor characteristics. In aerated poultry slurries α values have been related to effective viscosity and to mixed liquor total solids concentrations. The relationship between α and effective viscosity reported for aerated poultry manure is presented in Figure 4.14. While relating α to viscosity represents a sound analytical approach, utilization of this information is cumbersome due to the difficulties of measuring viscosity of the mixed liquor. Knowledge of the relationship between α and mixed liquor total solids (MLTS) concentrations appears to be of greater practical value. MLTS and viscosity in the mixed liquor are interrelated since the viscosity increases as the MLTS increases. Research results (1, 35) indicate that α has an average value of about one at MLTS concentrations of less than 20,000 mg/ℓ. As MLTS concentrations increase beyond that point, α values decrease to 0.4 at 55,000 mg/ℓ. The relationship between α and MLTS concentration is presented in Figure 4.15. Analysis of the data of Hashimoto and Chen (36) relating α to MLTS concentrations produced a similar relationship. In order to facilitate inclusion of the concept of α into process design, the mathematical relationships noted in Figure 4.16 will be used to estimate α values. These relationships were developed from the data presented in Figure 4.15.

In aerated poultry manure slurries, β has been reported to be independent of total solids concentrations ranging from 1 to 6 percent (36). The average value of β for 50 observations was reported to be 0.97 with a + 0.05 standard deviation.

It should be recognized that the quantity of oxygen actually transferred by an aeration unit (Equation 4.15) is a function of the dissolved oxygen deficit, $C_s - C_L$. As the dissolved oxygen deficit increases, the mass of oxygen transferred per unit time also increases. Since energy consumption by the aeration unit is fixed by physical constraints, the presence of high residual dissolved oxygen concentrations in the mixed liquor, C_L, reduces the oxygen transfer efficiency, i.e., the mass of oxygen per unit energy consumed. This results in increased operating costs. Thus design values for C_L should be no greater than 1 to 2 mg/ℓ for nitrifying systems (16). Lower values of C_L have been demonstrated to be satisfactory for odor control where nitrification is not desired (2).

4.6 Aeration System Process Design

An oxidation ditch or any other type of aeration system for poultry wastes can be designed and operated either as a continuously loaded batch reactor or as a continuous flow reactor. With the continuously loaded batch method, the ditch would be emptied periodically, refilled with tapwater, and the system restarted. This mode of operation has advantages in simplicity of operation

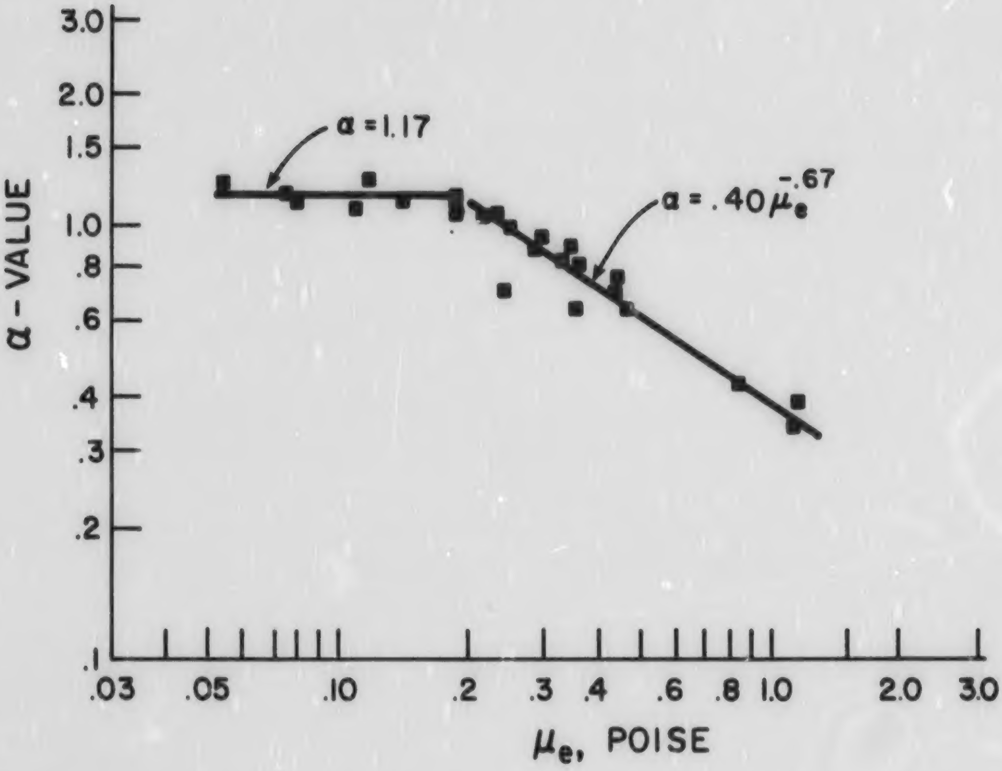

Figure 4.14. Effect of effective viscosity (μ_e) on relative oxygen transfer rate (α) (36).

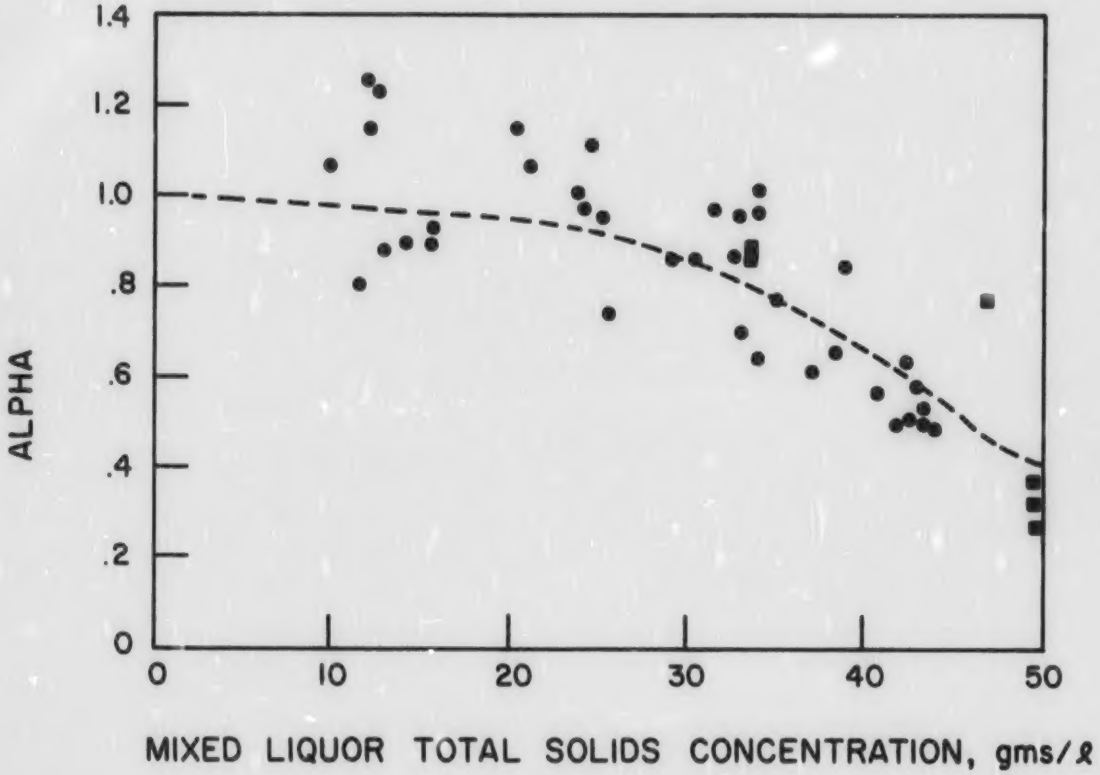

Figure 4.15. Relationship between α and mixed liquor total solids concentration in aerated poultry wastes (35).

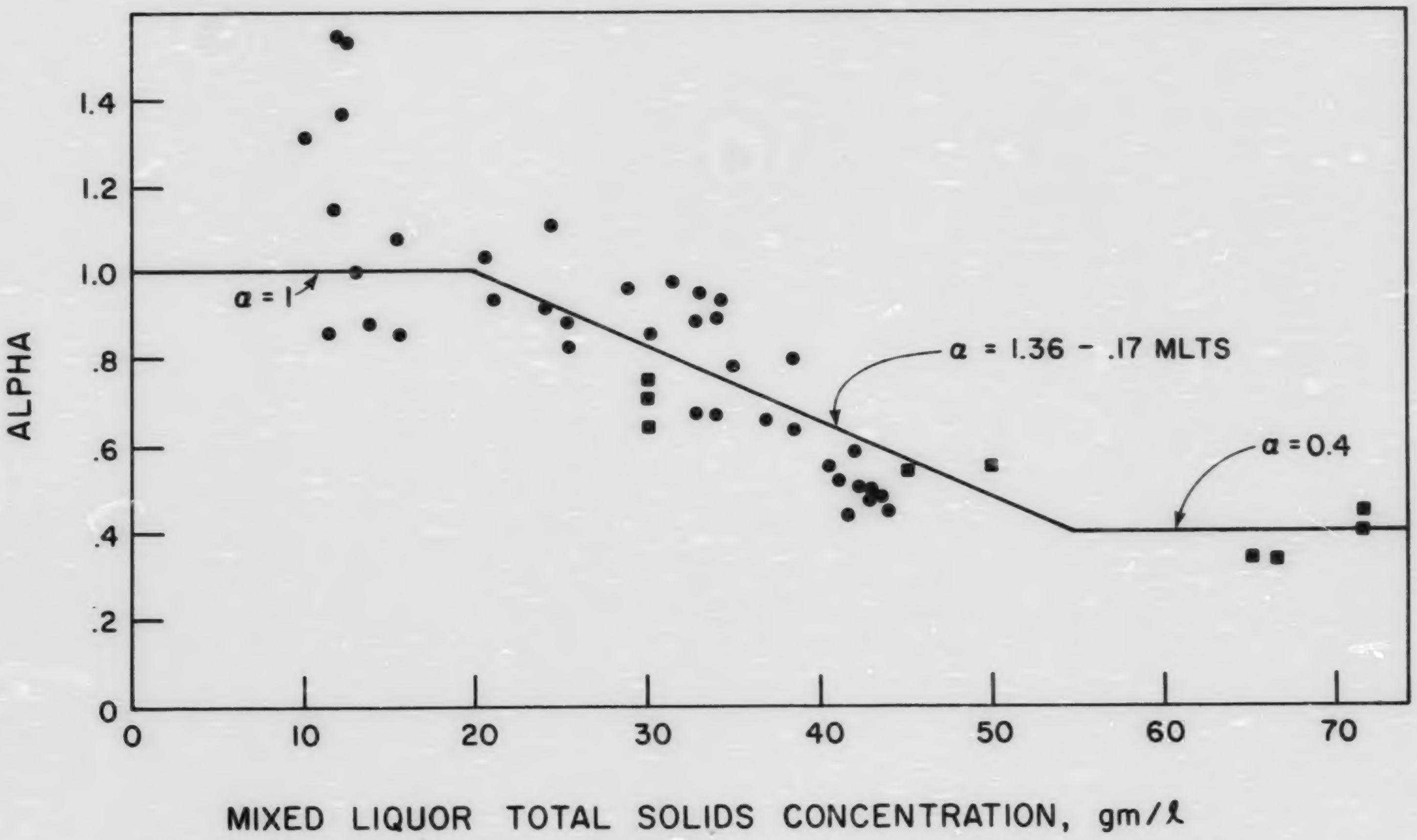

Figure 4.16. Effect of MLTS concentration on α in aerated poultry wastes (37).

and combines storage with stabilization. A major liability, however, is a low overall oxygenation efficiency. As the system mixed liquor total solids (MLTS) concentration increases with time, the value of α and thus oxygen transfer decreases (Figure 4.16 and Equation 4.15).

An alternative to the batch approach is a continuous flow process with control of MLTS concentration via continuous residual solids removal. This provides the opportunity to maximize oxygenation efficiency by maintenance of low MLTS concentrations. With this type of systems management, solids retention time (SRT) is a design and operating parameter allowing flexibility in matching the degree of waste stabilization with overall waste management objectives.

The process designs of both batch and continuous flow aeration systems for poultry wastes are based on the same fundamental concepts and relationships that have been previously discussed. However, design parameters such as SRT and MLTS concentrations which are independent variables in a continuous flow system are dependent variables in a batch system. Therefore, the design procedures for each system differ. The objective of this section is to present, by example, design methodology for each type of system. In order to facilitate presentation of design methodology, the relevant mathematical relationships will be summarized and values of constants are raw waste characteristics to be used will be presented.

4.6.1 Summary of Process Design Relationships, Kinetic Constants, and Raw Waste Characteristics

The underlying equation for the process design of aeration systems for poultry wastes is the empirical relationship between removal efficiency and SRT, Equation 4.19.

$$\text{Removal Efficiency, \%} = A(\text{SRT}) + B \qquad (4.19)$$

Values for the constants A and B for each parameter discussed previously in Section 4.5.2 are summarized in Table 4.4. Also included in this table are values defining the refractory fraction, R, for each parameter originally presented in Section 4.5.1.

Utilizing the results from Equation 4.19, the residual quantities for each parameter can be calculated using the following relationship:

$$S_1\text{, gm/bird-day} = [S_0\text{, gm/bird-day}] \times [\text{Removal Efficiency, \%/100}] \qquad (4.26)$$

where: S_0 = the quantity of any parameter as raw waste, gm/bird-day

S_1 = the quantity of the same parameter following stabilization, gm/bird-day

TABLE 4.4. FIXED CONSTANT VALUES FOR SUBSTRATE REMOVAL RELATIONSHIPS FOR POULTRY WASTES

	Fixed Constant Values		
Parameter	A	B	R
Total Solids	0.379	27.3	0.55
Volatile Solids	0.452	38.0	0.43
Chemical Oxygen Demand	0.294	25.2	0.60
Organic Nitrogen	0.539	47.0	0.31

It should be noted that be definition, S_1 cannot be less than the refractory fraction, R, for any characteristic.

The procedure for estimation of carbonaceous and nitrogenous oxygen demand is basedon the relationships presented in Equations 4.10 and 4.11. The modified form of these equations for design use are as follows:

$$\text{Carbonaceous oxygen demand, gm } O_2/\text{hr} = [(S_0\text{, gm COD/bird-day} - S_1\text{, gm COD/bird-day})(\text{Number of birds})]/24 \text{ hour/day} \quad (4.27)$$

$$\text{Nitrogenous oxygen demand, gm } O_2/\text{hr} = [(S_0\text{, gm ON/bird-day} - S_1\text{, gm ON/bird-day})(4.57)(\text{Number of birds})]/24 \text{ hours/day} \quad (4.28)$$

The total microbial oxygen demand is simply the sum of the carbonaceous and nitrogenous oxygen demands:

$$\text{Total oxygen demand} = \text{Carbonaceous oxygen demand} + \text{Nitrogenous oxygen demand} \quad (4.29)$$

As discussed in Section 4.5.3, the ratio of the value of the oxygen transfer coefficient, K_La, in tapwater to that under process conditions, α, in aerated poultry wastes decreases as MLTS concentrations increase. Thus, the oxygenation capacity of an aeration unit required to meet a constant microbial oxygen demand increases as MLTS concentration increases (Equation 4.15). The mathematical relationships which define α in relation to MLTS concentrations (Figure 4.17) are:

$$\text{For MLTS} \leq 20 \text{ gm}/\ell,\ \alpha = 1 \tag{4.30}$$

$$\text{For MLTS} > 20 \text{ gm}/\ell \text{ and } < 55 \text{ gm}/\ell,\quad \alpha = 1.36 - .017 \text{ MLTS, gm}/\ell \tag{4.31}$$

$$\text{For MLTS} \geq 55 \text{ gm}/\ell,\ \alpha = 0.4 \tag{4.32}$$

The required oxygen capacity at zero mixed liquor residual dissolved oxygen concentration can be determined by the following relationship:

$$\text{Oxygenation capacity, gm } O_2/\text{hr} = (\text{Oxygen demand, gm/hr})/\alpha \tag{4.33}$$

The subsequent examples of design methodology will utilize the raw manure characteristics presented in the following table. For procedures to estimate raw waste characteristics for specific situations, the reader is referred to Chapter 2.

TABLE 4.5. RAW WASTE CHARACTERISTICS USED FOR DESIGN EXAMPLES

Parameter	Production gm/bird-day
Total Solids	32.6
Volatile Solids	25.1
Chemical Oxygen Demand	28.0
Organic Nitrogen	1.94

4.6.2 Batch System Process Design Methodology

The design of a continuously loaded, batch aeration system involves two independent process design variables. They are system volume per bird and cumulative time of operation for each batch cycle. For this mode of operation, the average solids retention time (SRT) is:

$$\text{Average SRT} = \text{cumulative time of operation} \div 2 \qquad (4.35)$$

Thus, SRT is a dependent variable which continually increases over the operating period for the batch unit. As the time of operation and therefore SRT increases, the treatment efficiency for each waste characterization parameter also increases until the limits of the biodegradable fraction are reached at which point treatment efficiency becomes constant. This two step phenomena is reflected in the rate of microbial oxygen demand which increases until maximum treatment efficiency is attained and then becomes constant.

The increase in MLTS concentration as well as concentrations of other parameters follow a similar pattern. At levels below maximum treatment efficiency, the accumulation of total solids (TS), volatile solids (VS), chemical oxygen demand (COD), and organic nitrogen (ON) consist of unstabilized, biodegradable as well as refractory fractions. As maximum treatment efficiency is reached, rates of accumulation decrease and then become constant. Of particular interest are total solids due to the effect of increasing MLTS concentrations on α (Equations 4.30 through 4.32) and ultimately on required oxygenation capacity to meet a specific microbial oxygen demand (Equation 4.34).

The following is a summary of the steps in the process design of a continuously loaded, batch aeration system for poultry manure.

A. Measure manure production and determine characteristics or estimate these values using Equations 2.1 and 2.2 and the poultry waste characteristics presented in Table 2.4 (Chapter 2).

B. Select design values for system volume per bird and a time period in the batch operating cycle.

C. Calculate the average SRT using Equation 4.34.

D. Determine removal efficiencies for total solids (TS), volatile solids (VS), chemical oxygen demand (COD), and organic nitrogen (ON) using Equation 4.19 and the appropriate constants from Table 4.4.

E. Compute the residual quantities of each waste characterization parameter using Equation 4.26 with the previously calculated treatment efficiencies and the established raw waste characteristics.

F. Determine carbonaceous, nitrogenous, and total oxygen demands from Equations 4.27 through 4.29.

G. Calculate the mixed liquor concentrations for each parameter using the following relationship.

Mixed liquor concentration, gm/ℓ =
[(S_1, gm/bird-day)(Time of operation, days)] ÷
(volume/bird, ℓ/bird)

H. Identify the value for α corresponding to the MLTS concentration using the appropriate relationship (Equations 4.30 through 4.32).

I. Compute aeration capacities required to meet carbonaceous, nitrogenous, and total oxygen demands using Equation 4.33.

As an illustration of batch aeration design process, the following design example will outline required steps for the process design of a system for 30,000 birds.

A. For this example, raw waste characteristics presented in Table 4.5 will be used.

B. Design system volume is 20 ℓ/bird and the design time period per batch cycle is 30 days.

C. Average SRT (Equation 4.34) is

Average SRT = 30 days ÷ 2 = 15 days

D. For a 15 day SRT, removal efficiencies for each waste characterization parameter (Equation 4.19 and Table 4.4) are:

- TS removal efficiency, % = 0.379 (15 days) + 27.3 = 33.0%
- VS removal efficiency, % = 0.452 (15 days) + 38.0 = 44.8%
- COD removal efficiency, % = 0.294 (15 days) + 25.2 = 29.6%
- ON removal efficiency, % = 0.539 (15 days) + 47.0 = 55.1%

E. From Equation 4.26, the calculated treatment efficiencies, and the raw wastes characteristics (S_o) (Table 4.5), the residual quantities for each waste characterization parameter are:

- S[illegible]S/bird-day = 32.6 gm TS/bird-day x
  [illegible]1 - (33.0/100)] = 21.8 gm TS/bird-day
- S_1, gm VS/bi[illegible] 25.1 gm VS/bird-day x
  [1 - (44.[illegible]100)] = 13.8 gm TS/bird-day
- S_1, gm COD/bird-day = 28.0 gm COD/bird-day x
  [1 - (29.6/100)] = 19.7 gm COD/bird-day

- S_1, gm ON/bird-day = 1.94 gm ON/bird-day x
  [1 - (55.1/100)] = 0.87 gm ON/bird-day

F. Carbonaceous, nitrogenous, and total oxygen demands (Equations 4.27 through 4.29) are:

- Carbonaceous oxygen demand, gm O_2/hr = [(28.0 gm COD/bird-day -
  19.7 gm COD/bird-day)(30,000 birds)] ÷
  24 hr/day = 10,375 gms O_2/hr or 10.4 kg O_2/hr
- Nitrogenous oxygen demand, gm O_2/hr = (1.94 gm ON/bird-day -
  0.87 gm ON/bird-day)(4.57) (30,000 birds)] ÷
  24 hr/day = 6,112 gm O_2/hr or 6.1 kg O_2/hr
- Total oxygen demand, kg O_2/hr = 10.4 + 6.1 = 16.5 kg O_2/hr

G. Mixed liquor concentrations at day 30 of operation from the calculated values for residual quantities will be:

- MLTS, gm/ℓ = [(21.8 gm TS/bird-day)(30 days)] ÷
  20 ℓ/bird = 32.7 gm TS/ℓ
- MLVS, gm/ℓ = [(13.8 gm VS/bird-day)(30 days)] ÷
  20 ℓ/bird = 20.7 gm VS/ℓ
- MLCOD, gm/ℓ = [(19.7 gm COD/bird-day)(30 days)] ÷
  20 ℓ/bird = 29.5 gm COD/ℓ
- MLON, gm/ℓ = [(0.87 gm ON/bird-day)(30 days)] ÷
  20 ℓ/bird = 1.30 gm ON/ℓ

H. For a MLTS concentration of 32.7 gm/ℓ, the predicted value of α (Equation 4.31) is:

$$\alpha = 1.36 - 0.17(32.7) = 0.80$$

I. Required aeration capacities on day 30 of operation (Equation 4.33) are:

- Carbonaceous oxygenation capacity, kg O_2/hr = 10.4 kg O_2/hr ÷
  0.80 = 13 kg O_2/hr
- Nitrogenous oxygenation capacity, kg O_2/hr = 6.1 kg O_2/hr ÷
  0.80 = 7.6 kg O_2/hr
- Total oxygenation capacity, kg O_2/hr = 16.5 kg O_2/hr ÷
  0.80 = 20.6 kg O_2/hr

The same procedure was used to determine treatment efficiency, oxygen demand, mixed liquor characteristics, and oxygenation requirements at 60 days. A comparison between 30 and 60 days is presented in Table 4.6.

TABLE 4.6. COMPARISON OF PROCESS DESIGN COMPUTATIONS FOR 30 AND 60 DAYS OF SYSTEM OPERATION

Parameter	30 Days	60 Days
Treatment Removal Efficiency, %		
Total Solids	33.0	38.7
Volatile Solids	44.8	51.6
Chemical Oxygen Demand	29.6	34.0
Organic Nitrogen	55.1	63.2
Residual Quantities, gm/bird-day		
Total Solids	21.8	20.0
Volatile Solids	13.8	12.1
Chemical Oxygen Demand	19.7	18.5
Organic NItrogen	0.87	0.71
Microbial Oxygen Demand, kg O_2/hr		
Carbonaceous	10.4	11.9
Nitrogenous	6.1	7.0
Total	16.5	18.9
Mixed Liquor Concentrations, gm/ℓ		
Total Solids	32.7	60.0
Volatile Solids	20.7	36.3
Chemical Oxygen Demand	29.5	55.5
Organic Nitrogen	1.30	2.13
Alpha (α)	0.80	0.40
Required Oxygenation Capacity, kg O_2/hr		
Carbonaceous	13.0	29.8
Nitrogenous	7.6	17.5
Total	20.6	47.3

As shown, slight increases in treatment efficiency occur with comparable increases in microbial oxygen demands between 30 and 60 days. Residual quantities of each parameter accumulating in the system per bird-day decrease slightly. However, a large increase in mixed liquor concentrations occurs. The increase in MLTS concentration results in a 50% decrease in the value of α resulting in a sizable increase in the required oxygenation capacity to satisfy the microbial oxygen demand. If a design objective were to provide 60 days of storage, the aeration equipment would have to be sized to meet the final oxygenation requirements. However, over aeration would occur until the MLTS concentration reached 55 gms/ℓ ($\alpha = 0.4$, Equation 4.32), resulting in excessive operating costs. Procedures to optimize design will be considered in detail in the next chapter.

4.6.3 Continuous Flow System Process Design Methodology

The design of a continuous flow aeration system differs from a batch system in that SRT and MLTS concentration are independent design variables. In these systems, the desired level of treatment efficiency consistent with overall waste management objectives can be achieved by selecting the appropriate SRT value. At constant levels of treatment efficiencies for COD and organic nitrogen, microbial oxygen demand remains constant. In that SRT is held constant by removal of excess solids, MLTS concentration is also constant as is α and required oxygenation capacity. The desired value for MLTS concentration determines the system volume with volume decreasing as MLTS values increase.

The following is a summary of the steps in the process design of a continuous flow aeration system for poultry wastes.

A. Measure manure production and determine characteristics or estimate these values using Equations 2.1 and 2.2 and the poultry waste characteristics presented in Table 2.4 (Chapter 2).

B. Select design values for SRT and MLTS concentration.

C. Determine removal efficiencies for total solids (TS), volatile solids (VS), chemical oxygen demand (COD), and organic nitrogen (ON) using Equation 4.19 and the appropriate constants from Table 4.4.

D. Compute the residual quantities of each waste characterization parameter using Equation 4.26 with the previously calculated treatment efficiencies and the established raw waste characteristics.

E. Determine carbonaceous, nitrogenous, and total oxygen demands from Equations 4.27 through 4.29.

F. Identify the value for α corresponding to the design value for MLTS concentration using the appropriate relationship (Equations 4.30 through 4.32).

G. Compute aeration capacities required to meet carbonaceous, nitrogenous, and total oxygen demands using Equation 4.33.

H. Calculate mixed liquor concentrations of VS, COD, and ON from the previously calculated residual quantities.

I. Determine system volume, the quantity of residual solids to be removed to maintain an equilibrium SRT and MLTS concentration, and the volume of mixed liquor to be withdrawn to achieve the desired residual solids removal using the following relationships:

- System volume, ℓ = [S_1, gm TS/bird-day)(No. of birds)
  (SRT, days) ÷ (MLTS concentration, gm/ℓ)
- Residual solids removal, gm/day =
  (S_1, gm TS/bird-day) (No. of birds)
- Flow rate for residual solids removal, ℓ/day =
  (gm residual TS/day) ÷ (MLTS concentration, gm/ℓ)

As an illustration of continuous flow aeration design process, the following design example will outline the required steps for the process design of a system for 30,000 birds.

A. For this example, raw waste characteristics presented in Table 4.5 will be used.

B. The design value for SRT is 20 days and the design MLTS concentration is 10 gm/ℓ.

C. For a 20 day SRT, removal efficiencies for each waste characterization parameter (Equation 4.19 and Table 4.4) are:

- TS treatment efficiency, % = 0.379(10) + 27.3 = 31.1%
- VS treatment efficiency, % = 0.452(10) + 38.0 = 42.5%
- COD treatment efficiency, % = 0.294(10) + 25.2 = 28.1%
- ON treatment efficiency, % = 0.539(10) + 47.0 = 52.4%

D. From Equation 4.26, the calculated treatment efficiencies and the raw waste characteristics (S_o) (Table 4.5), the residual quantities for each waste characterization parameter are:

- S_1, gm TS/bird-day = 32.6 gm TS/bird-day x
  [1 - (31.1/100)] = 22.5 gm TS/bird-day
- S_1, gm VS/bird-day = 25.1 gm VS/bird-day x
  [1 - (42.5/100)] = 14.4 gm VS/bird-day
- S_1, gm COD/bird-day = 28.0 gm COD/bird-day x
  [1 - (28.1/100)] = 20.1 gm COD/bird-day

- S_1, gm ON/bird-day = 1.94 gm ON/bird-day x [1 - (52.4/100)] = 0.92 gm ON/bird-day

E. Carbonaceous, nitrogenous, and total oxygen demands (Equations 4.27 through 4.39) are:

- Carbonaceous oxygen demand, gm O_2/hr = [(28.0 gm COD/bird-day - 20.1 gm COD/bird-day) (30,000 birds)] ÷ 24 hr/day = 9875 gm O_2/hr or 9.9 kg O_2/hr
- Nitrogenous oxygen demand, gm O_2/hr = [(1.94 gm ON/bird-day - 0.92 gm ON/bird-day) (4.57) (30,000 birds] ÷ 24 hr/day = 5827 gm O_2/hr or 5.8 kg O_2/hr
- Total oxygen demand, kg O_2/hr = 9.9 + 5.8 = 15.7 kg O_2/hr

F. For a MLTS concentration of 10 gm/ℓ, the predicted value of α (Equation 4.30) is:

$$\alpha = 1.0$$

G. Required aeration capacities will be equal to the respective carbonaceous, nitrogenous, and total oxygen demands at a zero mixed liquor dissolved oxygen concentration since α has a value of unity (Equation 4.33).

H. The mixed liquor concentrations of VS, COD, and ON for a MLTS concentration of 10 gm/ℓ will be:

- (X gm MLVS/ℓ) x (27.5 gm TS/bird-day) = (14.4 gm VS/bird-day) x (10 gm MLTS/ℓ) = 6.4 gm MLVS/ℓ
- (X gm MLCOD/ℓ) x (22.5 gm TS/bird-day) = (20.1 gm COD/bird-day) x (10 gm MLTS/ℓ) = 8.9 gm MLCOD/ℓ
- (X gm MLON/ℓ) x (22.5 gm TS/bird-day) = (0.92 gm ON/bird-day) x (10 gm MLTS/ℓ) = 0.41 gm MLON/ℓ

I. - System volume, ℓ = [(22.5 gm TS/bird-day) (30,000 birds) (20 days)] ÷ 10 gm TS/ℓ = 1.35×10^6 or 4.5 ℓ/bird

- Residual solids removal, gm TS/day = (22.5 gm TS/bird-day) (30,000 birds) = 675,000 gm or 6.75 kg TS/day
- Flow rate for residual solids removal, ℓ/day = (675,000 gm TS/day) ÷ (10 gm TS/ℓ) = 67,500 ℓ of mixed liquor/day

The same procedure was used to develop a process design at a MLTS concentration of 35 gm/ℓ. Since SRT remains constant, treatment efficiencies, residual quantities, and microbial oxygen demand remain constant. However, α, required oxygenation capacity, system volume, and volume of mixed liquor removal for residual solids removal do change. A comparison of these values for MLTS concentrations of 10 and 35 gm/ℓ is presented in Table 4.7.

TABLE 4.7. COMPARISON OF PROCESS DESIGN COMPUTATIONS FOR MLTS CONCENTRATIONS OF 10 AND 35 GM/ℓ

Parameter	10 gm/ℓ	35 gm/ℓ
Alpha (α)	1.0	0.76
Required Oxygenation Capacity, kg O_2/hr		
Carbonaceous	9.9	13.0
Nitrogenous	5.8	7.6
Total	15.7	20.6
System Volume, ℓ/bird	45.0	12.8
Flow Rate for Residual Solids Removal, ℓ/day	67,500	19,286

As can be seen in Table 4.7, an increase in the design MLTS concentration increases required oxygenation capacity. However, system volume and the required flow rate for residual solids removal decrease significantly. Hence a trade-off exists between aeration costs and ultimate disposal costs. A more detailed examination of the effects of variation of MLTS concentrations and SRT will be discussed in the next chapter.

4.7 Physical Design Considerations

Presentation of details of the structural aspects of oxidation ditch design is beyond the scope of this manual. Assistance in this area is available from sources such as the Cooperative Extension Service. However, a discussion of several aspects of physical design which have a direct bearing on process performance appears appropriate. Included will be discussion of:

A. Aeration unit evaluation and selection;

B. Mixing requirements and oxidation ditch channel design;

C. Liquid-solids separation;

D. Potential problems and miscellaneous design details.

4.7.1 Aeration Unit Selection

One of the most important and complex steps in the design of any aerobic waste treatment system is aeration unit selection. Since the energy required to drive the aeration unit will be the major operating cost, the efficiency of the aeration unit, i.e., mass of oxygen transferred per unit energy consumed, is of considerable importance. Aeration units for oxidation ditches are available from several manufacturers. Due to differences in design, performance characteristics vary among units. Therefore, it is important to understand how aeration units are evaluated and rated.

The oxygen transfer characteristics of an aeration unit in tapwater serve as the standard method for equipment characterization. The technique most commonly used to evaluate oxygen transfer in tapwater is the non-steady state chemical method (38). This test involves the use of sodium sulfite (Na_2SO_3) in the presence of a catalyst, cobalt chloride ($CoCl_2$) to deplete the dissolved oxygen of the water in the test basin.

Following the commencement of aeration, the increase in dissolved oxygen concentration with time is determined. These data are then used to determine the oxygen transfer coefficient, K_La, utilizing Equation 4.14.

$$\frac{dC}{dt} = K_La\,(C_s - C_L) \qquad (4.14)$$

A semi-logrithmic plot of the dissolved oxygen deficit ($C_s - C_L$) versus time should produce a straight line, the slope of which is K_La (Figure 4.17).

Since oxygen transfer varies with temperature, experimental values of K_La are normally corrected to 20°C using the following relationship:

$$K_La_{20°C} = \frac{K_La_T}{\theta^{(T-20)}} \qquad (4.35)$$

where: $K_La_{20°C}$ = the value of K_La at 20°C

θ = the temperature correction factor for the system

T = the water temperature, °C

The value most commonly used for the temperature correction factor (θ) is 1.024 (16). The experimentally determined value of K_La is then used in the calculation of the oxygenation capacity of the aeration unit tested (Equation 4.15).

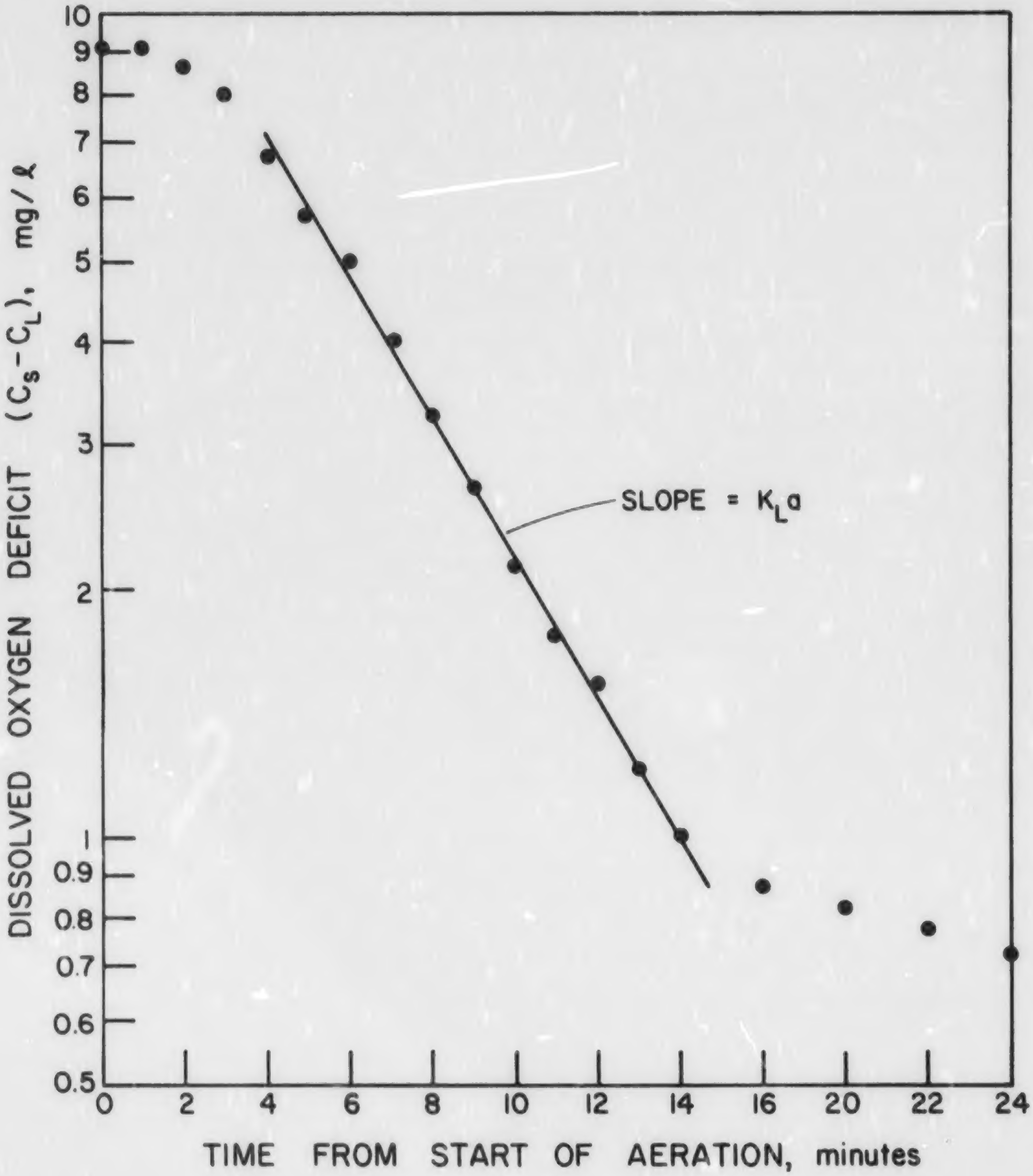

Figure 4.17. Determination of K_La in tap water.

$$N = \alpha K_L a_{20°C} (\beta C_s - C_L) (V) \qquad (4.15)$$

For tapwater, both α and β have values of unity.

Normally, energy consumption is measured during oxygen transfer studies thus permitting determination of the overall oxygen transfer efficiency, i.e., kg O_2 per gross kw-hr (lb O_2 per hp-hr). However, some manufacturers express oxygen transfer efficiency in terms of mass of oxygen transferred per unit power required by the aeration unit, i.e., kg O_2 per net kw (lb O_2 per brake hp). This practice excludes motor efficiency and results in a higher value for oxygen transfer efficiency. Therefore, care should be exercised when comprаring performance characteristics to be sure a common basis is being used.

Once the details of process design are complete and an aeration unit supplier has been chosen, the selection of a properly sized aeration unit should be the joint responsibility of the designer and the equipment manufacturer. The designers role should be to specify both the required rate of oxygen transfer and ditch velocity. This entails identification of anticipated operating conditions such as residual dissolved oxygen concentration, α and β factors, and temperature. Information concerning design mixed liquor velocity, ditch geometry, and maximum expected mixed liquor total solids (MLTS) concentration should also be included.

Once performance specifications and operating conditions are delineated, the equipment manufacturer should determine equipment requirements. This appears to be logical in that the manufacturer is most familiar with his equipment by virtue of testing and experience.

Designers should be aware that values for both the oxygen transfer coefficient, K_La, and pumping capacity determined under test conditions are a function not only of the aeration unit but also the test basin. Therefore, performance may vary. For these reasons, the use of performance specifications have been suggested to insure that aeration equipment will perform as expected (39). In the field of domestic waste treatment, it has been reported that in 16 different aeration tests less than 50 percent of the aeration equipment meet specifications (40).

Several methods of performance testing are available. These include non-steady chemical test, steady state microbial method, and the non-steady state microbial method. The non-steady state chemical method has been described earlier in this section. Descriptions of the steady and non-steady state microbial methods are available (16). The practice of performance testing should benefit not only the owner and designer but also the manufacturer by increasing his knowledge of equipment performance under a broad range of conditions.

4.7.2 Mixing Requirements and Oxidation Ditch Channel Design

The accumulation of settled solids in oxidation ditch channels is an often cited problem in discussions of oxidation ditches stabilizing animal wastes (2, 26, 31, 41, 42, 43). However, this problem has received little attention. An early misconception concerning sediment accumulation in these systems was that an equilibrium would be reached. Results of a full scale demonstration study of oxidation ditch stabilization of poultry wastes (2) has shown that the above assumption is untrue. In that study, initial mixed liquor velocity was not adequate to prevent settling. It was observed that sediment accumulation is accelerated resulting in a further decrease in velocity. This process was observed to continue until the mixed liquor velocity approached zero which occurred on several occasions.

This phenomenon can be understood by considering circulation in an oxidation ditch in terms of the Manning uniform equation for open channel flow (Equation 4.36).

$$V = \frac{1.486}{N} R^{2/3} S^{1/2} \qquad (4.36)$$

where: V = velocity, length/time

N = coefficient of roughness, dimensionless

R = hydraulic radius (cross-sectional area divided by the wetted perimeter), length

S = slope of the energy grade line, length/length

Assuming a constant energy input and therefore a constant equivalent to the slope of the energy grade line, this equation predicts that velocity will decrease as the coefficient of roughness increases and/or as the hydraulic radius decreases. Sediment accumulations cause both to occur.

As discussed by Chow (44), several factors affect the coefficient of roughness. Included are surface roughness and channel irregularity. Surface roughness is a function of the shape and size of the grains of the material forming the wetted perimeter. A significant difference should not exist between concrete and poultry manure solids. The suggested value of N for a concrete-lined channel in good condition is 0.014 (45). However, sediment accumulations can significantly affect channel irregularity (Figure 18). Irregularity can increase the value of N to as much as 0.021 (44).

Decreasing mixed liquor velocity due to sediment accumulation not only accelerates settling but also decreases mixing and oxygen transport. Thus, sediment accumulations can adversely affect the biological waste stabilization process possibly resulting in process failure. Therefore, the mixed liquor design velocity for an oxidation ditch should equal or exceed the scour velocity necessary to keep the heaviest manure particles in suspension.

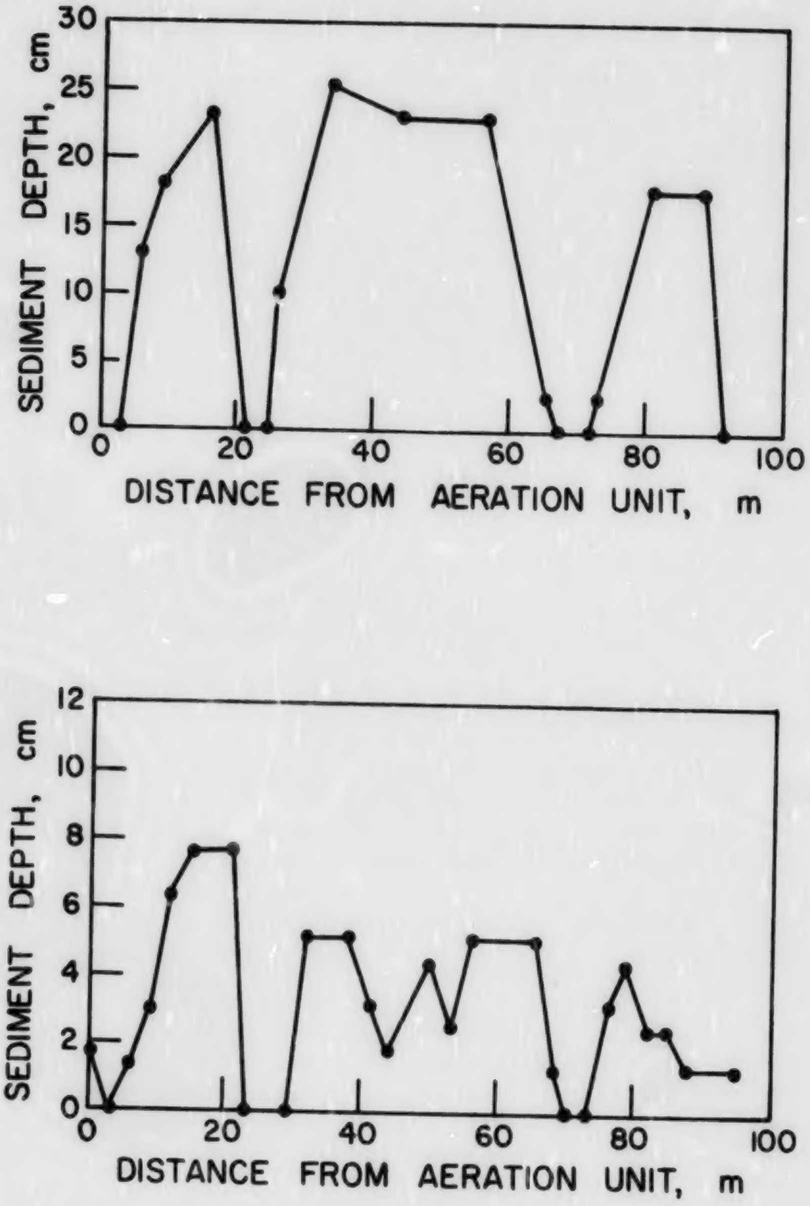

Figure 4.18. Observed patterns of sediment accumulation in oxidation ditches receiving poultry wastes (2).

The velocity necessary to keep the heaviest poultry manure particles in suspension can be calculated using the following relationship:

$$V_H = {\frac{8k(s-1)gd}{f}}^{1/2} \qquad (4.37)$$

where: V_H = horizontal velocity that will produce scour, length/time

s = specific gravity of particles, mass/volume

d = diameter of particles, length

k = constant dependent on the type of material being scoured, dimensionless

f = Darey-Weisbach friction factor, dimensionless

g = acceleration due to gravity, length/time^2

Using the following values (Table 4.8), the scour velocity for the heaviest particles in poultry manure was calculated to be 0.53 m/sec (1.74 ft/sec).

TABLE 4.8. VALUES USED TO ESTIMATE THE SCOUR VELOCITY FOR POULTRY MANURE

s = 2 gm/cm^3 (46)*

d = 1.19 mm, maximum (46)

k = 0.06 (47)

f = 0.02 (47)

* Numbers in parentheses refer to data sources.

The energy required to maintain the desired velocity in an oxidation ditch can be equated to the energy loss due to friction. Wong-Chong, et al. (48) have suggested the use of the Fanning (Darcy) equation (Equation 4.38) to estimate frictional energy losses in these systems.

$$H_f = \frac{2LV^2f}{D_Hg} \qquad (4.38)$$

where: H_f = energy loss due to friction, length

D_H = hydraulic diameter, length

f = Fanning's friction factor, dimensionless

g = acceleration due to gravity, length/time^2

L = total straight length of open channel, length

V = flow velocity in the channel, length/time

While this approach is valid for estimating frictional losses in linear channel sections (49), a method to calculate these losses in semi-circular channel sections is not possible. However, general relationships affecting friction losses in these channels are known. Chow (44) states that the coefficient of curve resistance, f_c, is a function of several factors which are:

R_n = Reynolds number

y/b = ratio of liquid depth to channel width

$\alpha/180°$ = ratio of angle of curvature to 180°

r_c/b = ratio of radius of curvature to channel width

General characteristics of the relationship between each of these factors and f_c have been presented by Shukry (50) based upon experimental studies involving water. A summary of these relationships are as follows:

A. The coefficient, f_c, decreases as the Reynolds number increases up to the value of $R = 3 \times 10^4$. Beyond that point, f_c increased.

B. The coefficient f_c decreases as the ratio of liquid depth to channel width (y/b) increases.

C. The coefficient f_c decreases as the ratio of the radius of curvature to width (r_c/b) increases.

D. The coefficient f_c increases as the ratio of angle of curvature to 180° ($\alpha/180°$) increases.

The effect of f_c on energy loss due to curve resistance in terms of velocity head can be expressed as follows:

$$h_f = f_c \frac{V^2}{2g} \qquad (4.39)$$

where: h_f = velocity head loss, length

V = mean velocity in the section, length/time

g = acceleration due to gravity, length/time^2

At this time, the determination of the required energy input to maintain a desired mixed liquor velocity remains an art rather than a science. However, it is clear that a major fraction of the frictional energy losses in these systems occurs in the semi-circular connecting channels. In a comparison of two oxidation ditches differing significantly only in the radius of curvature of the semi-circular sections, it was shown that mixed liquor velocity can be increased without increasing energy input by increasing the r_c/b ratio (2).

In designing oxidation ditch channels, it should be recognized that the current practice of adapting channel geometry to animal locations increases energy requirements for mixing. Particularly in the poultry industry, the above practice results in semi-circular channels with small radius of curvatures. Also, most oxidation ditches for animal wastes are designed to operate with shallow liquid depths thus having small ratios of liquid depth to channel width.

An alternative is to design the ditch channel to minimize energy losses due to friction and therefore energy requirements for mixing. However, this approach will require large radii of curvature and possibly not having the ditch channel directly below the animals. This eliminates the advantage of direct deposition of the wastes into the treatment unit. Equipment such as scrapers or flushing units will be required at least for a portion of the wastes. It should be recognized that trade-offs exist. However, these trade-offs can not be analyzed quantitatively at present. Thus, judgement and experience must be relied upon for design decisions.

4.7.3 Liquid-Solids Separation

As noted earlier, the operation of an aeration system for poultry wastes as a continuous flow process has several advantages. It permits operation at an equilibrium mixed liquor total solids (MLTS) concentration of less than 20,000 mg/ℓ which results in maximum oxygen transfer efficiency. Of equal importance is that the solids retention time (SRT) becomes a design and operating parameter allowing flexibility in the desired degree of waste stabilization.

In order to maintain an equilibrium MLTS concentration, continuous removal of residual total solids is necessary. However, the volume of manure added per day is not sufficient to create a significant overflow. Based upon the poultry manure characteristics presented in Table 2.5 (Chapter 2), the volume of manure produced by 30,000 birds is approximately 3700 ℓ/day (980 gal/day). For a continuous flow aeration system with an SRT of 20 days and a MLTS concentration of 35 gm/ℓ, 3700 ℓ represents only one percent of the system volume and 20 percent of the required flow rate for residual solids removal (Table 4.7). These calculations assume no evaporation. Therefore, actual percentages will be lower. Experience with pilot plant scale aeration units has shown that evaporation exceeds the volume of manure input for poultry wastes. Therefore, it is necessary to create a flow for the removal of the solids. Several approaches are available. One would be to continually add tapwater to create a continuous overflow into a storage lagoon. However, ultimate disposal requirements would increase due to the added water.

A second method would be to operate the system as a draw and fill reactor. Some variations in SRT and MLTS concentrations would occur but ultimate disposal requirements would be reduced. A third approach would be to utilize a liquid-solid separation process and return the liquid to the system to create flow. While this is the most complex alternative, it is the most reasonable in terms of ultimate disposal if a reasonable degree of solids thickening can be achieved.

Research concerning liquid-solids separation processes for poultry wastes has been limited. Three processes; gravitational settling, screening, and centrifugation; have been evaluated to varying degrees. It is the objective of this section to present available information concerning these processes.

The use of gravitational settling for aerated poultry wastes has been examined under full scale conditions (2). Performance was reported to be less than satisfactory. This was attributed to the design approach which was based on overflow rates for domestic activated sludge. Results of subsequent laboratory studies has shown that the zone settling velocity (ZSV) of aerated poultry manure decreases rapidly as MLTS concentrations approach 10,000 mg/ℓ (Figure 4.19) (51). Beyond 10,000 mg/ℓ, zone settling velocities are minimal.

Using the clarification and thickening design approach presented by Lawrence (52) which is based upon the batch flux concept (53), design surface area requirements for clarification and thickening of aerated poultry wastes were examined. The relationship between surface area required for clarification (Figure 4.20) shows area requirements increase rapidly as MLTS concentrations exceed 6000 mg/ℓ. The relationship between surface area requirements for thickening and total solids concentration in clarifier underflow (Figure 4.21) suggests that 32,000 mg/ℓ represents the practical upper limit for concentration of residual solids in aerated poultry wastes. Thus, the feasibility of this approach appears to be questionable.

The use of centrifugation and screening has also been investigated but to a more limited degree. Centrifuge test results (Table 4.9) indicated that this process is capable of a high degree of solids removal from aerated poultry wastes. Also, the centrifugation process produced a concentrated sludge which can significantly reduce the volume of material requiring ultimate disposal in comparison to direct disposal of mixed liquor. While these results suggest that the process has significant potential, detailed information concerning optimum methods of operation, costs and ease of operation are lacking. Thus, comments on the feasibility of the process and a detailed discussion of design factors are not possible at this time.

Results of screening tests indicated that this process has only limited potential for liquid-solids separation of aerated poultry wastes (2). This is due to particle size distribution. Results of 200 mesh screening tests

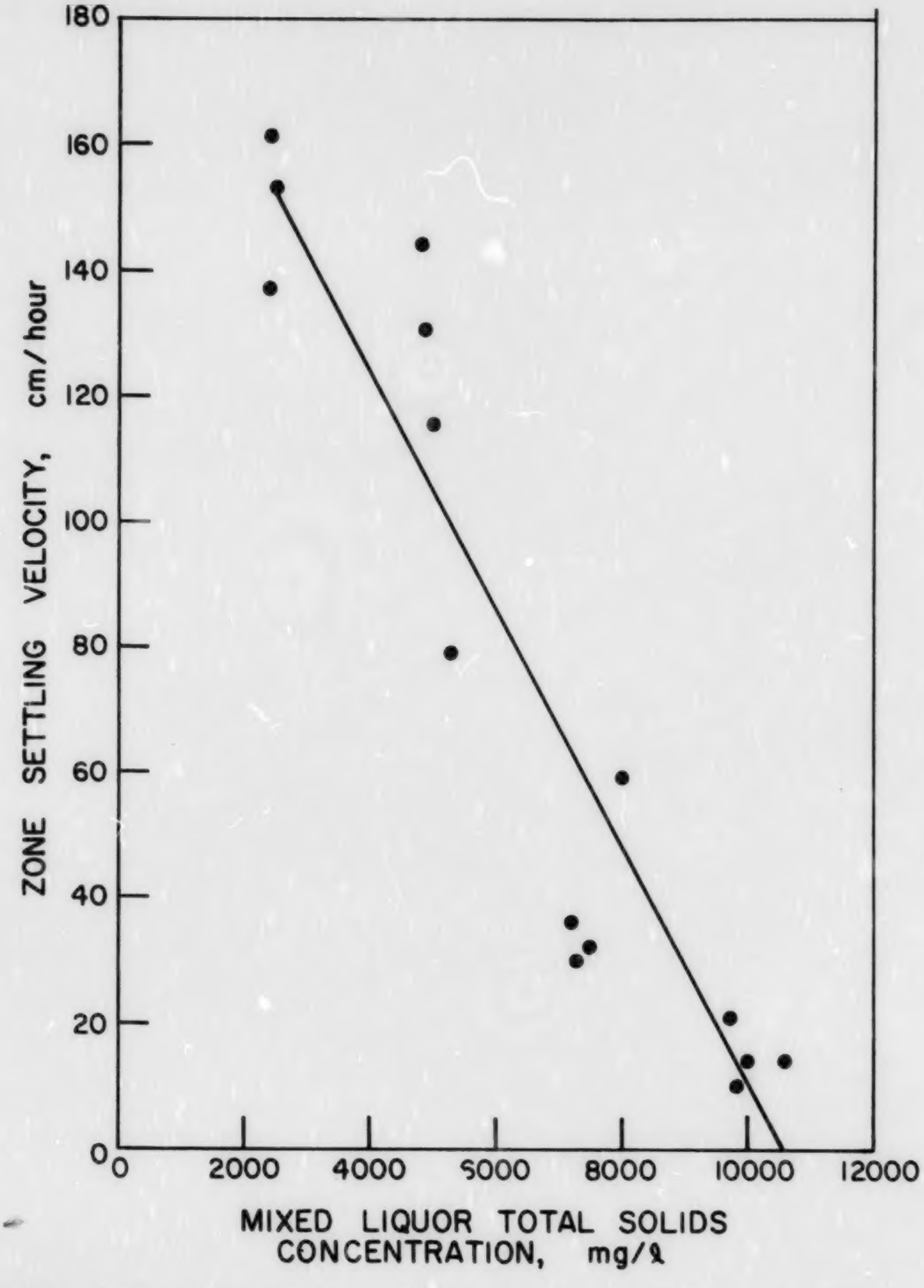

Figure 4.19. Zone settling velocity versus total solids concentration for aerated poultry wastes (51).

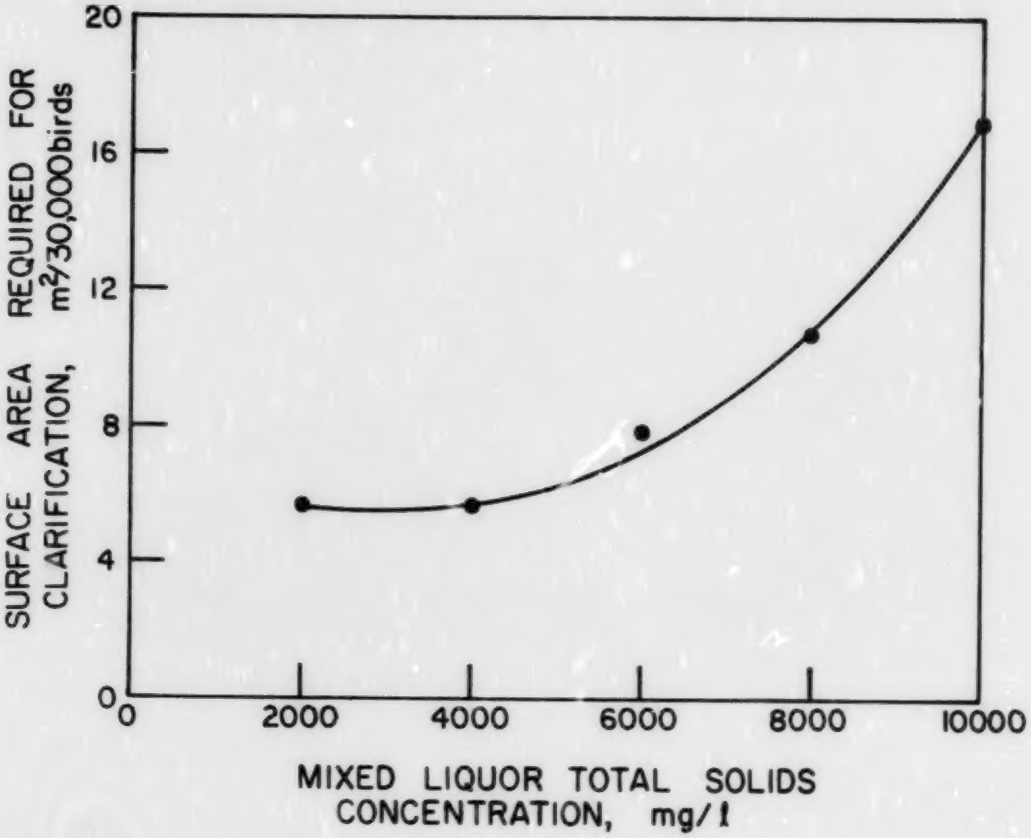

Figure 4.20. Dependence of clarifier surface area for clarification on mixed liquor total solids concentration for aerated poultry wastes (51).

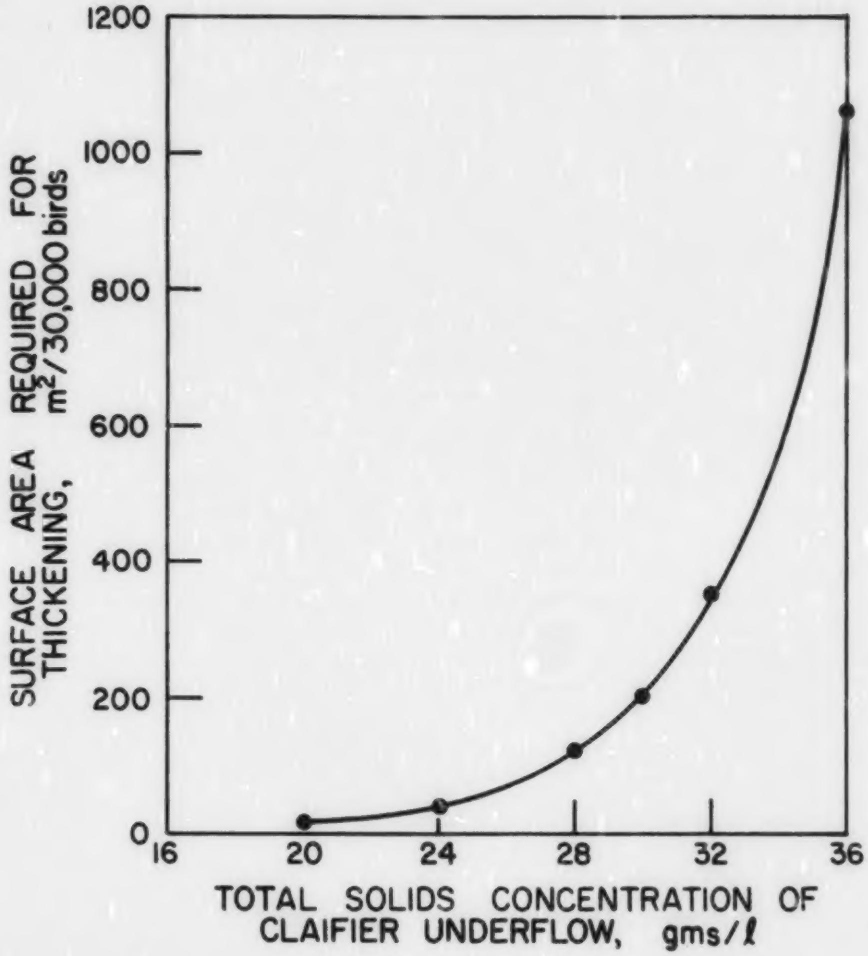

Figure 4.21. Dependence of clarifier surface area for thickening on underflow total solids concentration for aerated poultry wastes (51).

indicated that 60 to 80 percent of the suspended solids in aerated poultry wastes were less than 0.074 mm in diameter. While the use of finer screens 250 and 325 mesh, improved solids removal, they required reduced flow rates and decreased cake dry matter content. It was concluded that screening was only practical for removal of coarse solids and would have to be used in combination with another liquid-solids separation process for a continuous flow system.

Recently, several commercial equipment manufacturers have introduced roller presses for the separation and concentration of solids from animal wastes. At present, performance of these units with aerated poultry waste remains to be defined. Thus, the feasibility of these units is unclear. It is suggested that designers investigate the availability of newly developed information concerning these units before making design decisions concerning liquid-solids separation.

4.7.4 Potential Problems and Miscellaneous Design Details

Foam is probably the most common problem encountered in the operation of aeration systems for poultry and other animal manures. While a thin foam layer is not atypical of a well operating aeration system, the presence of an excessive quantity of foam is an indicator of a fundamental problem. There appear to be several different reasons for foaming. The following is a discussion of the various causes and solutions.

Foaming is a common occurrence during aeration system start-up. This is apparently due to an imbalance in the food to microorganism ratio due to an inadequate microbial populaton. If possible, the system should be seeded with mixed liquor from another aeration system or from the previous batch if a batch mode of operation is employed. An advantage of the continuous flow mode of operation is that repeated start-up situations are avoided. Gradual housing of hens where possible will also serve to reduce start-up foaming problems.

Excessive foaming is typical of systems where the level of oxygen transfer is inadequate to meet the exerted carbonaceous oxygen demand. This results in the production of surface active metabolic end-products and is usually accompanied by malodors. The solution to this type of foaming problem is to increase aeration capacity or to reduce the mixed liquor total solids concentration to increase oxygen transfer if possible.

Foaming problems have also been encountered in apparently well operating systems. McKinney and Bella (54) have suggested that accumulations of settled solids are responsible for foaming in these situations. The maintenance of adequate mixed liquor surface velocities in oxidation ditches is important in foam control in these systems. This provides a continuous breakdown of any foam by the aeration unit. The absence of structures such as overflow standpipes in the ditch channel which may hinder foam movement is important. Feathers which may form large floating mats can also restrict foam movement. Periodic removal of these feather accumulations may be necessary.

An often suggested strategy for foam control is the addition of vegetable or petroleum oil. This practice is at best a short term solution which does nothing to correct the fundamental problem. Moreover, the addition of petroleum oil may significantly reduce the ratio of K_La in the mixed liquor to K_La in tapwater, α, thus reducing oxygen transfer (Equation 4.15) (36). Therefore, this practice can intensify problems of foam and odor where oxygen transfer is inadequate. It is recommended that oil additions be only considered as a measure of last resort while more fundamental solutions are applied.

An advantage of aeration as compared to drying systems for poultry wastes is that leakage from bird watering systems will not adversely affect process performance. While it appears that a balance will exist between manure input and evaporation permitting maintenance of a constant system volume, significant watering system leakage will produce an overflow situation. The need for a collection and storage basin as well as increased ultimate disposal requirements will result.

Three types of watering systems are currently in use in the poultry industry. They are nipple valves, cups, and troughs. Experience indicates that in spite of manufacturer's claims, neither nipple valves nor cups will provide a reliable leak-free watering system. While trough watering systems require periodic cleaning, the potential for overflow is minimal. Therefore, it is suggested that trough water systems be used with aeration systems for poultry wastes.

Oxidation ditch aeration units, like other types of mechanical equipment, require regular maintenance as well as occasional repairs. The most frequently encountered mechanical problem with these units is bearing failure. Thus, accessibility for maintenance and repairs should be considered when determining the location of aeration units.

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CHAPTER 5

DESIGN APPROACHES

5.1 Introduction

In the two preceding chapters, the development of process design methodologies for high-rise, undercage drying and aeration systems for poultry wastes has been presented. Before either of these design procedures can be utilized, decisions concerning design variables which represent management options are necessary. In that these systems can be designed and operated over wide ranges of values for these variables, an understanding of how these variables affect performance is necessary. It is the objective of this chapter to discuss the impact of design decision alternatives on the operating characteristics of these systems and to present approaches to simulate system performance.

Included in this chapter will be descriptions of several computer programs designed to assist in the evaluation of alternative design decisions for specific situations. The computer language used for these programs is the WATFIV version of FORTRAN IV. In writing these programs, a primary objective was to make them understandable and usable by individuals having only limited exposure to the use of computers. Efficiency in programming may have been sacrificed in certain instances in the interest of charity. However, the impact on computation costs is negligible due to the simplicity of each program. The use of these programs, while not a prerequisite for design, provides ease in evaluating the effects of a wide range of values for process design variables for specific situations. The programs were employed in this manner to generate the information presented in the following discussion of design approaches for these systems.

5.2 High-Rise, Undercage Drying

The objective of the process design of a high-rise, undercage drying system is the determination of the drying air velocity necessary to provide moisture reduction to a specified value during the start-up phase of operation. This level of moisture reduction is important for ridge formation and biological heat production in the drying manure. Biological heat production is the critical factor in the high-rise drying process.

In a high-rise, undercage drying system, the magnitude of the required drying air velocity is dependent on the following independent process design variables:

A. Bird density, which is a function of the type of cage system and the number of birds per cage;

B. Feed energy content;

C. The specified manurial surface moisture content during the start-up phase of system operation.

An understanding of the relationships between these variables and design drying air velocity is necessary to identify optimum combinations of these variables for specific situations.

As noted in Chapter 3, it is not possible to design a high-rise, drying system to provide a specific final system moisture content. This is due to the inability to predict changes in vapor pressure differential due to biological heat production with time. However, it appears possible to simulate changes in system moisture content over time by describing the four variables that define manurial surface moisture content; area factor, moisture loading factor, drying air velocity, and vapor pressure differential; as time dependent variables. This provides an opportunity to evaluate various design variables such as the design value for manurial surface moisture content. It also provides a mechanism to analyse the effect of changes of time dependent variables such as vapor pressure differential. This section describes the nature of the relationships between the three independent process design variables and design drying air velocity and includes a discussion of an approach to simulate high-rise system performance over time.

5.2.1 High-Rise, Undercage Drying System Design

The process design of a high-rise, undercage drying system for poultry wastes requires specification of design values for bird density, the quantity of moisture excreted per bird-day, and the manurial surface moisture content during the start-up phase of system operation. Decisions concerning specifying design values for these variables should be based upon understanding the relationships between these factors and design drying air capacity.

Due to the possible combinations of cage systems and numbers of birds per cage (Tables 3.3 and 3.4), there are six possible design values for bird density. The relationship between bird density and design drying air velocity with all other variables held constant, is presented in Figure 5.1. Increases in bird density significantly affect drying air velocity design values. However, the ratio of bird density and design drying air velocity (Table 5.1) shows that this relationship is constant. Therefore, the unit drying air requirements are independent and any reduction in housing costs per bird will not be offset by increased costs associated with drying air circulation.

As discussed in Chapter 2, the quantity of moisture excreted per bird-day appears to be a function of feed metabolizable energy (ME) content (Figures 2.1 and 2.3). As feed ME content decreases, the quantity of moisture excreted and thus the evaporative capacity requirements of a high-rise drying system will increase. This translates into increased drying air velocity design values.

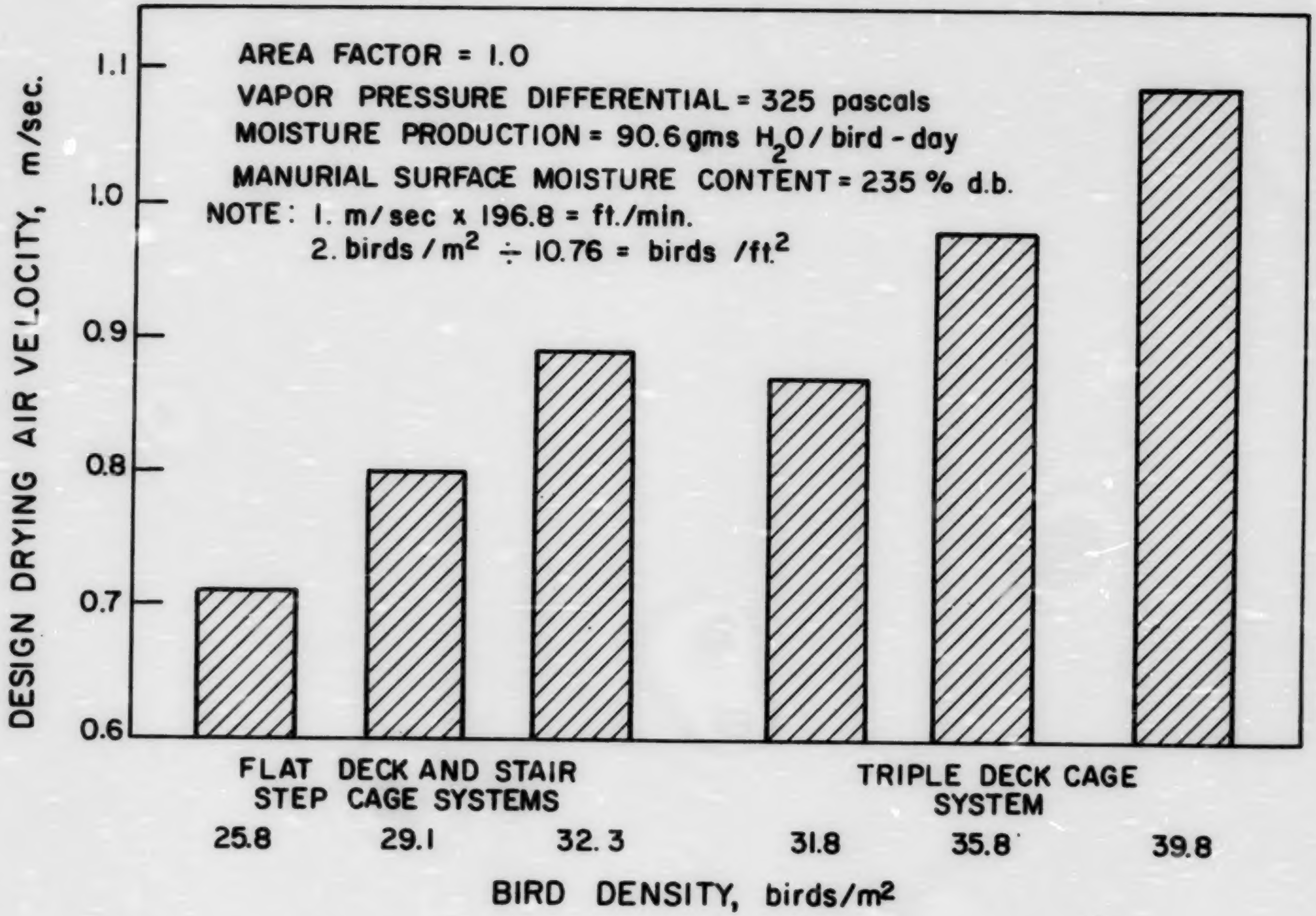

Figure 5.1. Effect of type of cage system and management practices (no. of birds/cage) on drying air velocity design requirements.

TABLE 5.1. RATIOS OF BIRD DENSITY TO DESIGN DRYING AIR VELOCITY

Bird Density, birds/m^2	Design Drying Air Velocity, m/sec	Bird Density/Design Drying Air Velocity Ratio
25.8	0.71	36.3
29.1	0.80	36.4
32.3	0.89	36.3
31.8	0.87	36.6
35.8	0.98	36.5
39.8	1.09	36.5

The relationship between design drying air velocity and the quantity of moisture excreted per bird-day is presented in Figure 5.2. Small changes in the quantity of moisture excreted per bird-day do not drastically change design drying air velocities. However, the desirability of minimizing the quantity of moisture excreted by utilizing feeds with a high ME content is illustrated by Figure 5.2.

The practice of utilizing feeds with high ME contents will serve to reduce costs associated with drying air circulation. The quantity of total solids produced will also be reduced (Figure 2.1). However, it should be recognized that the management decision to use a high ME feed can not be based solely on waste management factors. Nutritional aspects must be considered as well as possible economic trade-offs. It is possible that increased feed costs due to the use of a high ME feed could be equal to or greater than any waste management cost reductions.

The selection of a design value for manurial surface moisture content is perhaps the most ill-defined aspect of high-rise, undercage drying process design. The value selected must be conservative enough to insure successful system performance but not require an unreasonable design drying air velocity. The relationship between the design values for manurial surface moisture content and design drying air velocity is illustrated in Figure 5.3. As shown, the rate of change of design drying air velocity increases as the specified manurial surface moisture content decreases with 235 percent appearing to be a reasonable value in terms of design drying air velocity.

The largest propeller type fan available for agricultural application has a capacity of 9.44 m^3/sec (20,000 ft^3/min). A fan of this capacity will provide an average drying air velocity of 0.72 m/sec (143 ft/min) in a cross-section area of 13 m^2 (140 ft^2). This is one-half of the total manure storage cross-sectional area in a typical 2.2 m (40 ft) wide high-rise poultry house. Thus,

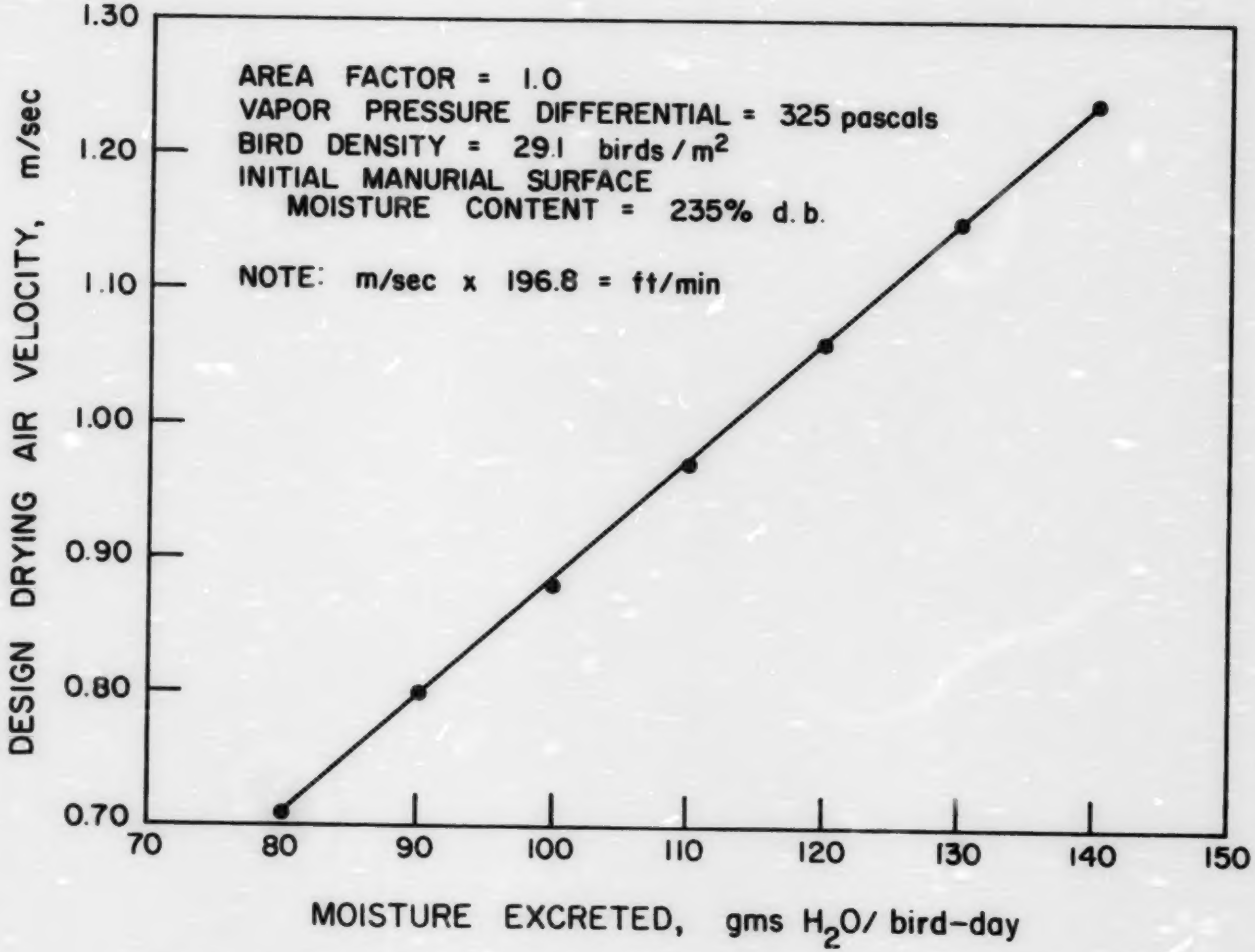

Figure 5.2. Relationship between quantity of moisture excreted and design drying air velocity.

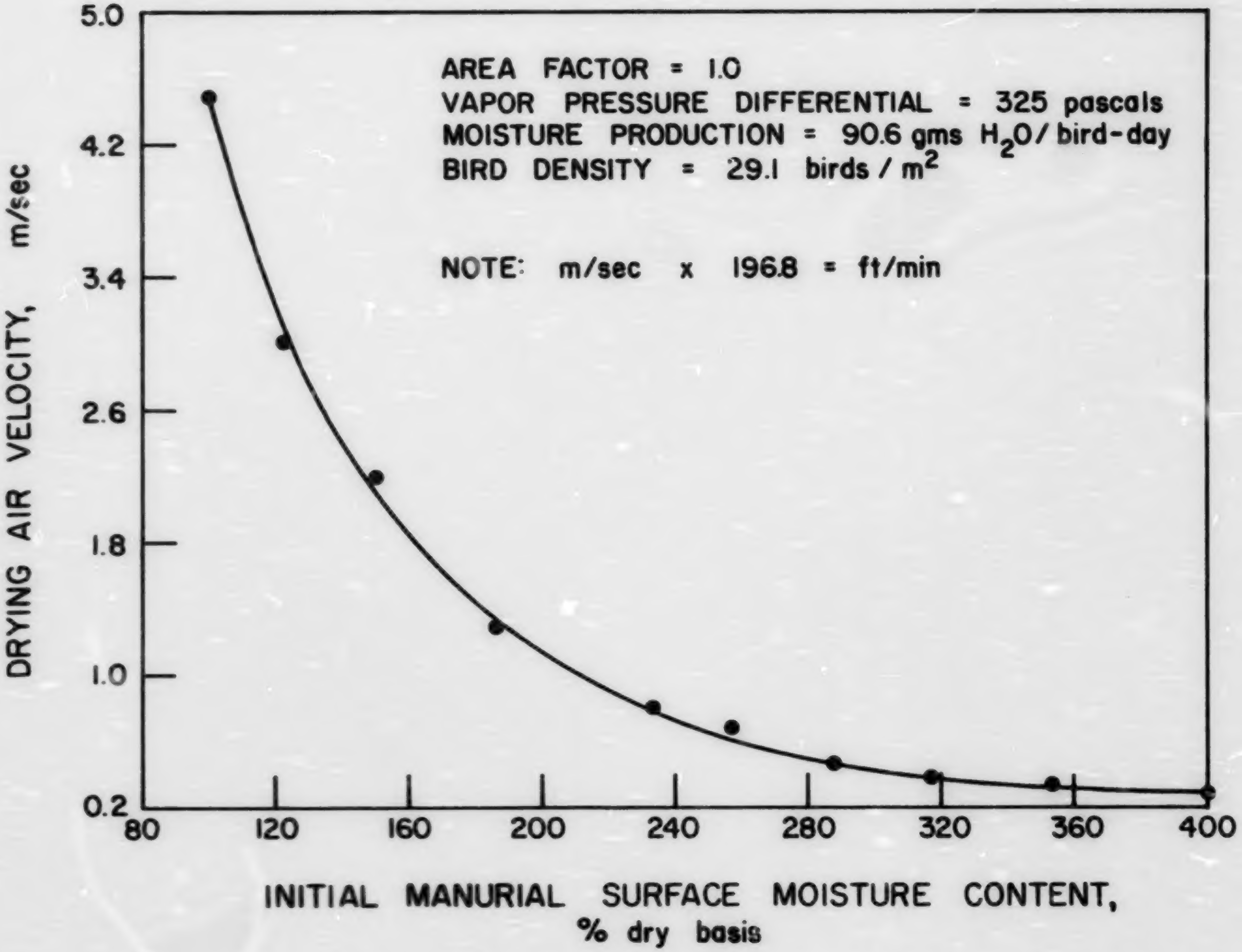

Figure 5.3. Relationship between initial manurial moisture content and design drying air velocity.

the design value of 235 percent, dry basis, (Table 3.5) appears reasonable in terms of both available equipment and past experience (Table 3.1).

The results of the preceding analyses show that both feed energy content and the specified manurial surface moisture content design decisions can significantly affect design drying air velocity and increase requirements per bird. However, increases in bird density do not increase drying air velocity requirements per bird. Thus, maximizing bird density to minimize housing costs will not be offset by increased waste management costs.

5.2.2 Simulation of System Performance

Although it is not possible to design a high-rise, undercage drying system to provide a specific final system moisture content, it does appear possible to simulate system performance over time and to predict a final system moisture content for specific patterns of change in vapor pressure differential with time that may be anticipated. This approach provides a method of evaluating the effect of design decisions such as decreasing design drying air velocity on system performance. It also provides a mechanism for evaluating different patterns of change in vapor pressure differential with time for a specific design.

A mathematical model was developed to predict changes in system moisture content with cumulative time of operation based on the hypothesis that system moisture content is simply the reflection of past surface moisture contents. This model considers area factor, bird density and thus the moisture loading factor, vapor pressure differential, and drying air velocity as time dependent variables. At specified increments in time of operation, values for manurial surface moisture content are computed. System moisture content is then calculated by averaging previously computed values for manurial surface moisture content.

In order to test the validity of this simulation approach, the performance of a full scale system was simulated and then compared with observed results (1). Area factor, bird density, vapor pressure differential, and drying air velocity were described as time dependent variables using available data from the full scale study. Using linear regression analysis of the observed change in the area factor with cumulative time of operation (Figure 3.8), the following relationship expressing the area factor at any time, T, in days (AFT) was mathematically defined.

$$AFT = 0.0016(T) + 1.0 \tag{5.1}$$

During the year of system operation which was simulated, mortality which results in decreased bird density followed a normal linear pattern. Losses averaged one percent of the number of hens housed per month. This translates mathematically as follows:

$$BDT = -0.01(T)(BDI) \quad (5.2)$$

where: BDI = initial bird density, birds/m^2

T = cumulative time of operation, days

BDT = bird density at any time, birds/m^2

Substituting BDT for BD in Equation 3.9, the moisture loading factor at any time (MLFT) can be estimated.

The change in vapor pressure differential with time was defined mathematically using both 1970-71 and 1971-72 data (Table 3.1 and Figure 3.13). Using regression analysis, these data were best described by two separate linear relationships. For values of T between 0 and 200 days:

$$VPDT = 2.3(T) + 238 \quad (5.3)$$

and for T between 200 and 360 days:

$$VPDT = 14.2(T) - 2148 \quad (5.4)$$

Based upon the design approach for determination of drying air fan velocity (Chapter 3), average drying air velocity at the beginning of system operation for 1971-72 was estimated to be 0.40 m/sec (1). Due to a decrease in manure storage cross-sectional area resulting from the accumulated manure, it was further estimated that average drying air velocity increased to 0.59 m/sec at the end of the 1971-72 cycle. Assuming that the velocity increase was linear over time, the average drying air velocity at any time in days (AVT) over the 1971-72 manure accumulation cycle was defined as:

$$AVT = 0.00045(T) + 0.40 \quad (5.5)$$

For this simulation, the reported values for this system of 99 gm H_2O/bird-day for moisture production and 29.1 birds/m^2 for initial bird density were used. The reader should understand that Equations 5.1 through 5.5 are specific for the system studied by Sobel and do not necessarily represent general relationships.

The results simulated by the model for manurial surface moisture content and average system moisture content are presented in Figure 5.4. These results indicate that surface moisture content decreases more rapidly than average system moisture content. This is due to the lack of additional drying once a manure surface ceases to be exposed due to subsequent manure depositions.

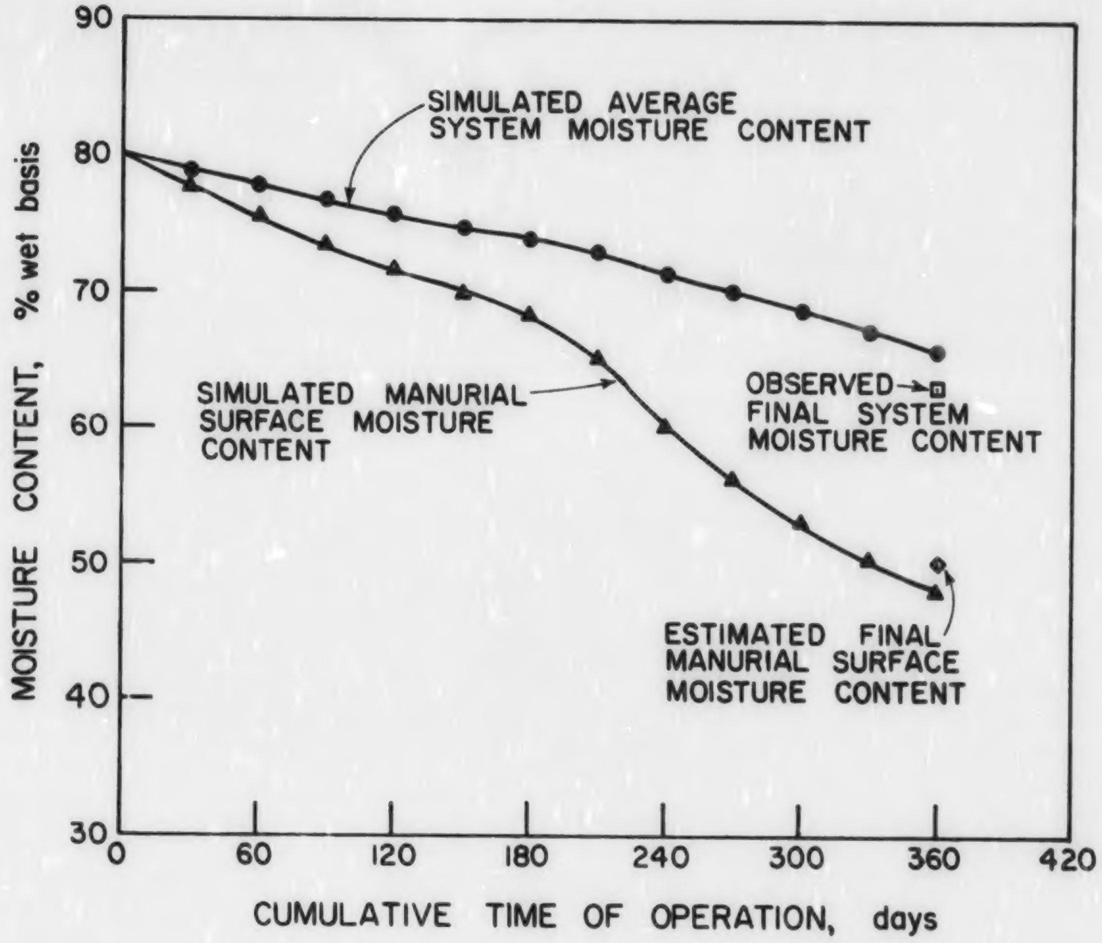

Figure 5.4. Simulated results from a high-rise, undercage drying system performance predictive model.

There is good agreement between the simulated final system moisture content on day 360 of 66 percent, wet basis (WB), and the observed value of 63 percent, WB (1). Average final manurial surface moisture content was not measured but was estimated to be 50 percent, WB. The simulated value was 48 percent, WB. Unfortunately, additional observed data concerning average surface and system moisture contents at intermediate points in time of system operation are lacking. This information would serve to confirm the accuracy or identify the limits of this simulation approach.

This model was used to evaluate the effects of variation in moisture production, initial drying air velocity, and initial bird density on final manurial surface and average system moisture contents at day 360 of system operation. Simulations were performed for the pattern of change in vapor pressure differential with cumulative time of operation expressed in Equations 5.3 and 5.4 (Table 3.1 and Figure 3.13). In addition, simulations utilizing only Equation 5.3 were carried out to assess the importance of the rapid increase in vapor pressure differential following 200 days of cumulative operation observed in full scale system evaluations (Figure 3.13). These results are presented in Table 5.2. Values in parentheses resulted from the lower rate of increase in vapor pressure differential expressed solely by Equation 5.3.

These results show that higher values for moisture production and/or bird density must be compensated for with higher design drying air velocity to provide satisfactory system performance. Based on experience, an average system moisture content at day 360 of system operation of 66 percent, WB, or less appears desirable.

Comparison of average system moisture contents for the two patterns of change in vapor pressure with time of operation serves to reinforce the importance of biological heat production and the resultant effect on vapor pressure differential in the high-rise drying process. While it appears that a drying air velocity of 0.4 m/sec will provide satisfactory system performance for 100 gm H_2O/bird-day and 29.1 birds/m^2 with significant biological heat production, a higher drying air velocity will be required if biological heat production is minimal. This can be translated into higher costs for equipment and operation.

This mathematical model provides a method to examine the effects of design variables and other factors on system performance. In the design of these systems, minimizing moisture production within the limits of practicality and providing conditions during the start-up phase of system operation conducive to biological heat production appear to be the most important factors.

5.2.3 Computer Design Programs

Two computer programs have been developed to assist in the process design of high-rise, undercage drying systems. The first program; high-rise, undercage drying design analysis; was designed to analyze the effects of variation in moisture production per bird-day, bird density, and the design value for manurial surface moisture content on design drying air velocity. This program is based on the process design equations, Equations 3.9 and 3.13. The second program, high-rise, undercage drying - simulation of system performance, was developed to predict system performance over time for various combinations of

TABLE 5.2. EFFECTS OF PROCESS DESIGN VARIABLES ON FINAL MANURIAL SURFACE AND SYSTEM MOISTURE CONTENTS IN A HIGH-RISE, UNDERCAGE DRYING SYSTEM

		Day 360	
		Manurial Surface Moisture Content, % WB	Average System Moisture Content, % WB
Initial drying air velocity	= 0.4 m/sec		
Initial bird density	= 29.1 birds/m^2		
Moisture production	= 80 gm/bird-day	45.4* (58.0)**	63.4 (67.1)
	= 100 gm/bird-day	48.2 (60.7)	65.8 (69.4)
	= 120 gm/bird-day	50.4 (62.8)	67.7 (71.3)
Moisture production	= 100 gm/bird-day		
Initial bird density	= 29.1 birds/m^2		
Initial drying air vel.	= 0.4 m/sec	48.2 (60.7)	65.8 (69.4)
	= 0.8 m/sec	39.7 (52.3)	58.2 (61.9)
	= 1.0 m/sec	37.1 (49.5)	55.6 (59.3)
Moisture production	= 100 gm/bird-day		
Initial drying air velocity	= 0.4 m/sec		
Initial bird density	= 29.1 birds/m^2	48.2 (60.7)	65.8 (69.4)
	= 32.3 birds/m^2	49.4 (61.9)	66.9 (70.5)
	= 39.8 birds/m^2	52.0 (64.5)	68.9 (72.5)

* For T = 0 through 200, VPDT = 2.3T + 238, and for T = 200 through 360, VPDT = 14.27 - 2148

** For T = 0 through 360, VPDT = 2.3T + 238 design values for moisture production per bird-day, bird density, and design drying air velocity. The mathematical model discussed in the previous section is the basis for this program. Flow diagrams and source listings for both programs are presented in the Appendix, Figures A-2 through A-5. The following is a brief description of user input and computed output for both programs.

The high-rise, undercage drying design analysis program is a combination of three subprograms for the sequential examination of moisture production, bird density, and the design manurial surface moisture content as variables. For this program, the user must specify the following:

A. Values for area factor and vapor pressure differential representative of start-up conditions ;

B. Values for manurial surface moisture content, dry basis (DB) and bird density and a range of values for moisture production;

C. Values for manurial surface moisture content, DB and moisture production, and a range of values for bird density;

D. Values for moisture production and bird density, and a range of values for manurial surface moisture content, DB.

For each combination of values; moisture production, bird density, and manurial surface moisture content, DB; this program will compute design drying air velocities for each value of the variable parameter in each combination.

For the second program; high-rise, undercage drying - simulation of system performance; the user must specify a set of design values for moisture production, initial drying air velocity, and initial bird density. For each set of design values, this program will compute manurial surface and average system moisture contents at specified time intervals over a one-year operating cycle.

5.3 Aerobic Biological Stabilization

Aeration systems for poultry wastes can be designed and operated as either batch or continuous flow reactors. The batch mode of operation combines storage with odor control and waste stabilization, whereas separate storage facilities are required with a continuous flow system. Both modes of operation are similar in that aeration requirements and volumetric ultimate disposal requirements are inversely related. Thus, trade-offs between aeration and ultimate disposal costs exist for both batch and continuous flow modes of operation.

While the process designs of these alternatives are based on the same fundamental concepts, the independent process design variables differ. In order to evaluate the trade-offs for each operational mode, an understanding of the relationships between the respective process design variables and aeration and ultimate disposal requirements is necessary. It is the objective of this section to describe the relationships between design variables and operating characteristics for each method of operation and to discuss the trade-offs created by various decisions concerning design variables.

The relationships presented in the following discussions are based on the raw waste characteristics for poultry manure presented in Table 4.5. It should be understood that while the general nature of the following relationships will not change, specific values will vary with changes in raw waste characteristics. Thus, in the design of specific systems, anticipated raw waste characteristics should be delineated for process design calculations.

5.3.1 Continuously Loaded, Batch Aeration System Design

A continuously loaded, batch aeration system has two independent process design variables. They are system volume per bird and the operating period for the batch cycle. Both aeration capacity and ultimate disposal requirements are dependent on these variables.

In a batch system, the solids retention time (SRT) is a dependent variable which continually increases with time of operation (Equation 4.34). Thus, removal efficiencies (Equations 4.20 through 4.23) and total carbonaceous and nitrogenous oxygen demands (Equations 4.27 and 4.28) will increase with time changes in both carbonaceous and nitrogenous oxygen demands as a function of cumulative batch system operation time are presented in Figure 5.5. In a batch system, nitrogenous oxygen demand increases until about day 80, at which point it becomes constant since the biodegradable limit of organic nitrogen in poultry manure is reached. The same patter occurs for carbonaceous oxygen demand which becomes constant at about day 110 of the batch operation. Thus, maximum removal of organic nitrogen and carbonaceous oxygen demand will occur within 80 and 100 days, respectively.

A characteristic of a continuously loaded, batch aeration system is he continual increase in the mixed liquor total solids (MLTS) concentration as the time of operation increases. This is due to the accumulation of unstabilized biodegradable and refractory fractions of total solids. The rate of change of MLTS concentration in a batch system is a function of both system volume per bird and cumulative time of operation. A comparison of the rates of increase of MLTS concentrations for system volumes of 20 ℓ/bird and 40 ℓ/bird is presented in Figure 5.6.

The rate of increase in MLTS concentration is non-linear and decreases with time of operation. This is due to the increase in SRT and hence increased biodegradable solids destruction. As system volume per bird increases, the operating period for a batch cycle to reach a maximum or desired MLTS concentration also increases. However, the increase in time is greater than that which would be provided solely by dilution. The difference is due to increased biodegradable solids destruction.

A comparison of calculated time periods to reach a MLTS concentration of 60 gm/ℓ for system volumes of 10 ℓ/bird through 40 ℓ/bird is presented in Figure 5.7. A 100 percent increase in system volume per bird, 20 ℓ/bird to 40 ℓ/bird, increases the time period to reach 60 gm MLTS/ℓ by 125 percent. The use of 60 gm as a maximum value for MLTS concentration in a batch aeration system should not be interpreted as the identification of an absolute upper limit for this

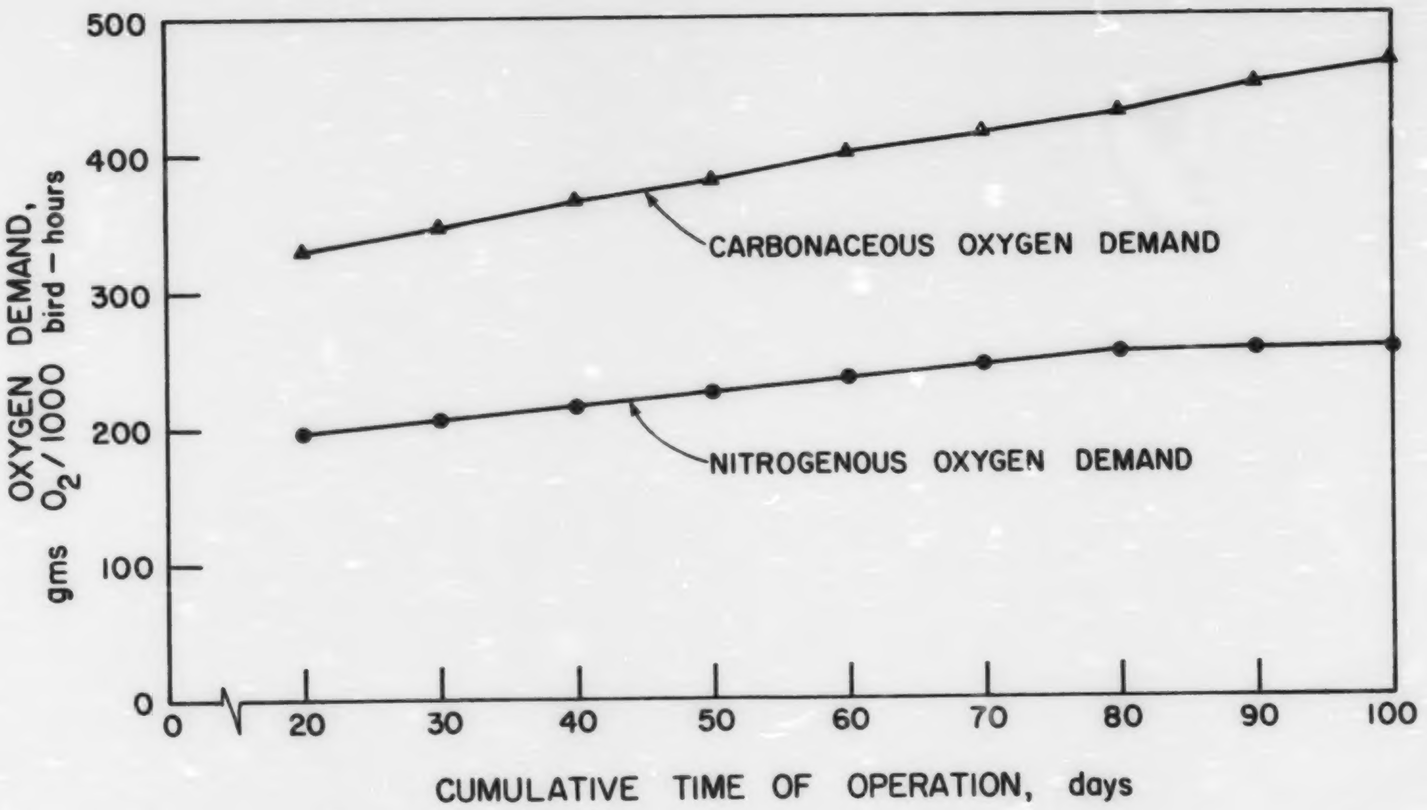

Figure 5.5. Changes in carbonaceous and nitrogenous oxygen demands in a batch aeration system for poultry wastes.

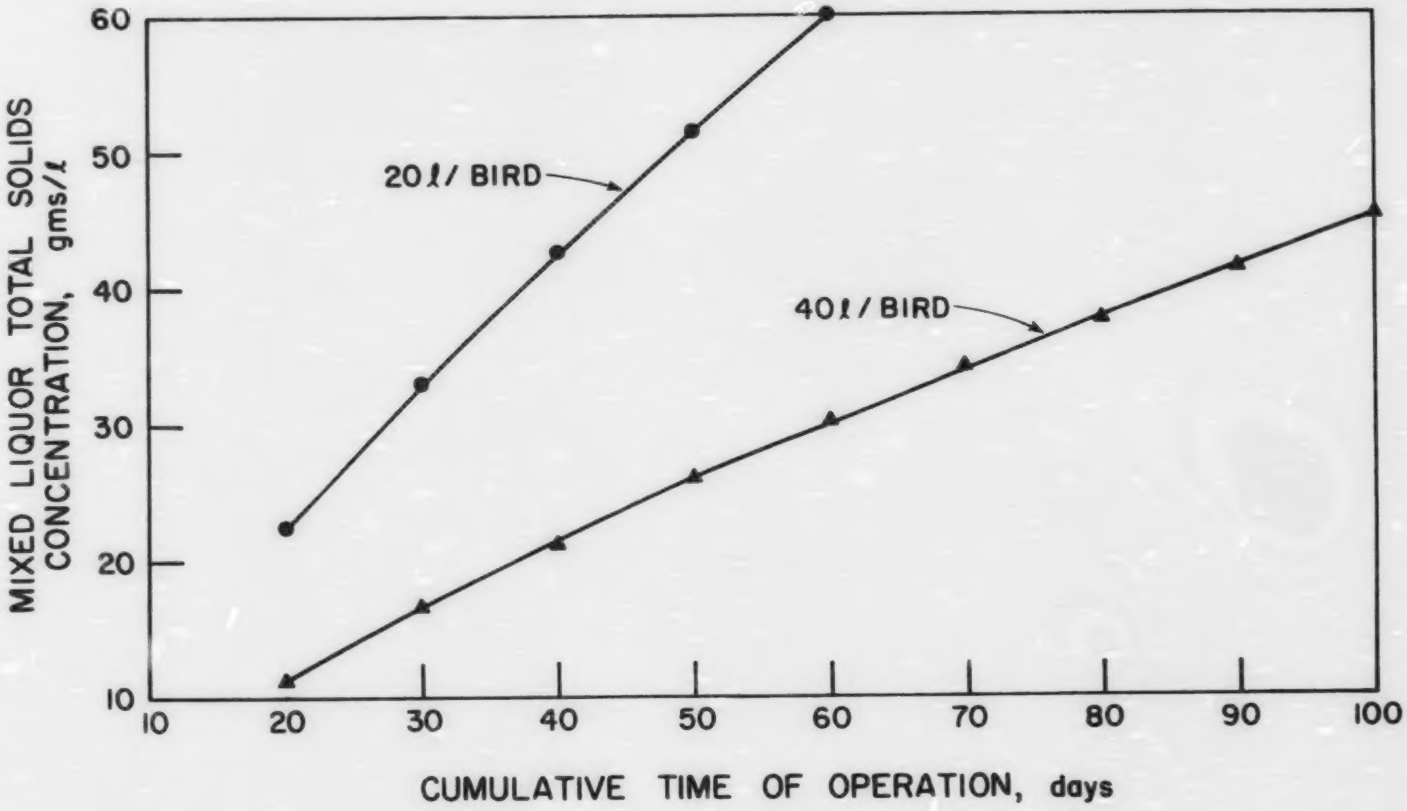

Figure 5.6. Comparison of rate of increase in MLTS concentration with time as a function of system volume per bird.

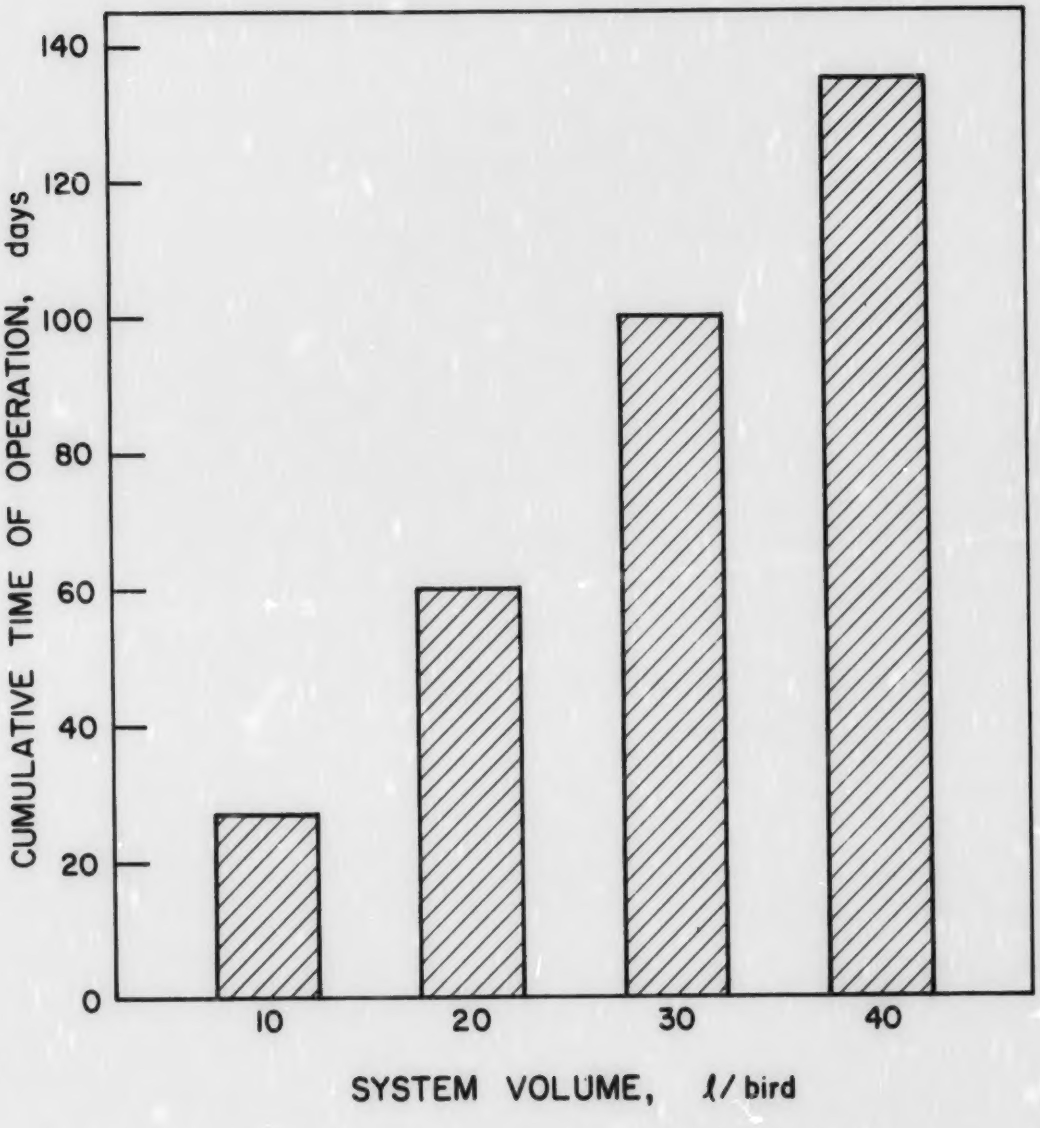

Figure 5.7. Cumulative time of batch system operation to reach a mixed liquor total solids concentration of 60 gm/ℓ.

parameter. However, when aeration capacity and mixing requirements are considered, an upper limit for MLTS concentrations of about 60 gm/ℓ appears practical.

The effect of increasing system volume per bird on ultimate disposal requirements is presented in Table 5.3. Increasing system volume up to 30 ℓ/bird will decrease yearly ultimate disposal requirements. Beyond 30 ℓ/bird, these requirements become essentially constant.

TABLE 5.3. ULTIMATE DISPOSAL REQUIREMENTS FOR A BATCH AERATION SYSTEM AS RELATED TO SYSTEM VOLUME PER BIRD

System Volume per Bird, ℓ/bird	Ultimate Disposal Requirements, ℓ/bird/year*
10	135
20	122
30	110
40	108

* Based upon a mixed liquor total solids concentration of 60 gm/ℓ.

The increase in MLTS concentration in a batch system is the mechanism by which storage of residual solids is provided. However, this phenomenon has an adverse effect on the efficiency of oxygen transfer. This results from the decrease in α, the ratio of the overall oxygen transfer coefficient, K_La, in the aerated manure to K_La in tapwater as MLTS concentration increases. The relationships between α and MLTS concentration for aerated poultry manure slurries have been presented in Equations 4.30 through 4.32. As α decreases, the aeration capacity necessary to meet a given microbial oxygen demand increases (Equation 4.33).

A comparison of carbonaceous oxygen demand and aeration capacity requirements with time of operation for a system volume of 30 ℓ/bird is presented in Figure 5.8. From day 20 through day 100, carbonaceous oxygen demand increases 40 percent, while required aeration capacity increases 254 percent. Reducing the time period of the batch cycle and therefore the maximum MLTS concentration will reduce aeration capacity requirements but will increase the volume of stabilized waste requiring ultimate disposal. A comparison of aeration and ultimate disposal requirements as a function of cumulative operation time for a system volume of 30 ℓ/bird is presented in Table 5.4. A plot of ultimate disposal versus aeration capacity requirements for system volumes of 20 ℓ/bird, 30 ℓ/bird, and 40 ℓ/bird (Figure 5.9) shows that this relationship is independent of system volume per bird. It also illustrates that beyond a required aeration capacity of about 500 gm O_2/1000 bird-hours, only minor decreases in

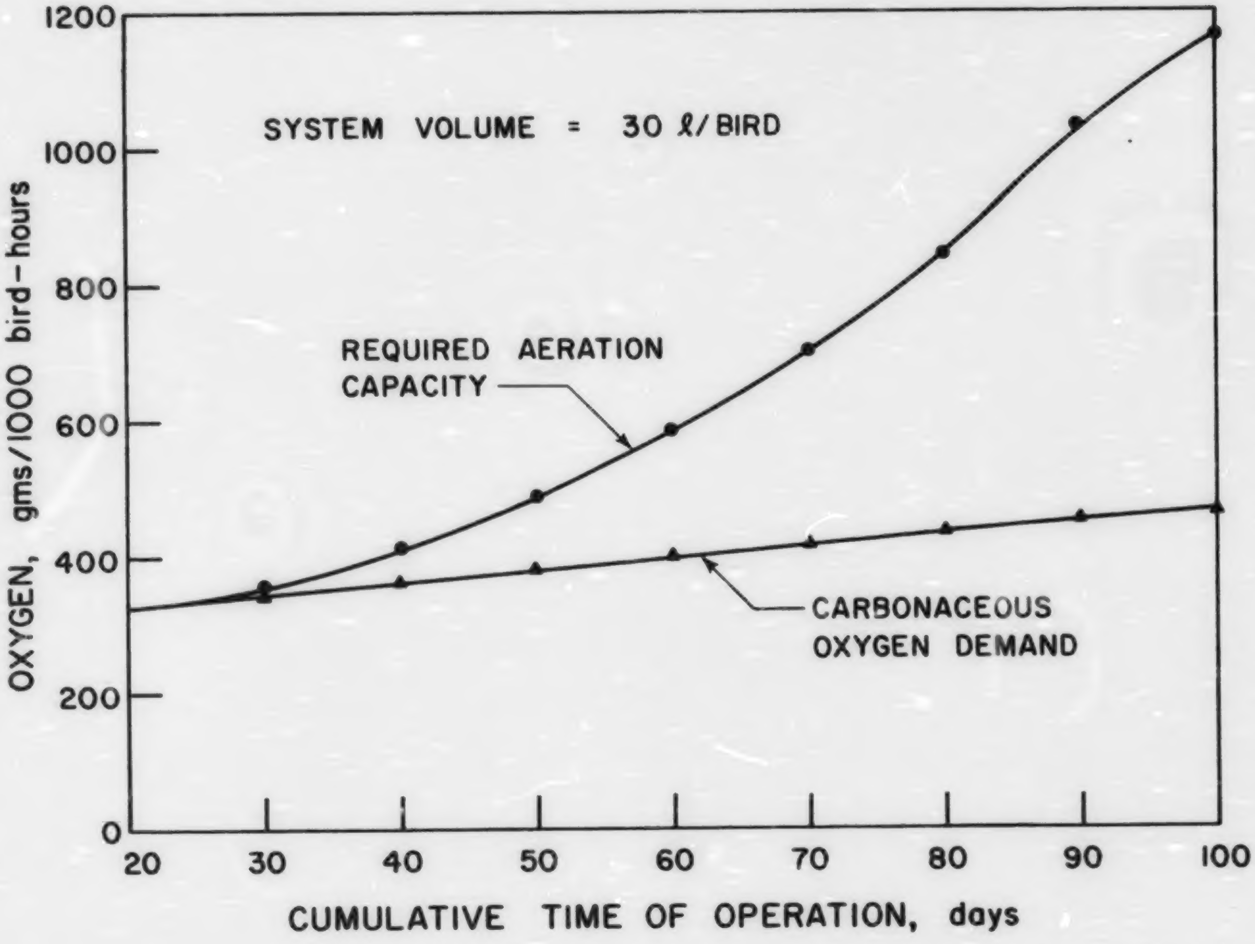

Figure 5.8. Comparison of carbonaceous oxygen demand and required aeration capacity over the operating period for a batch cycle.

TABLE 5.4. MAXIMUM AERATION CAPACITY AND ULTIMATE DISPOSAL REQUIREMENTS FOR A BATCH SYSTEM WITH VOLUME OF 30 ℓ/BIRD AS RELATED TO CUMULATIVE TIME OF OPERATION

Cumulative Time of Operation, days	Mixed Liquor Total Solids Concentration, gm/ℓ	Required Aeration Capacity, gm O_2/ 1000 bird-hours	Ultimate Disposal Requirements, ℓ/bird/year
20	15.0	329	548
30	21.8	350	365
40	28.3	413	274
50	34.3	490	219
60	40.0	584	182
70	45.2	700	156
80	50.0	846	137
90	54.4	1031	122
100	59.8	1165	110

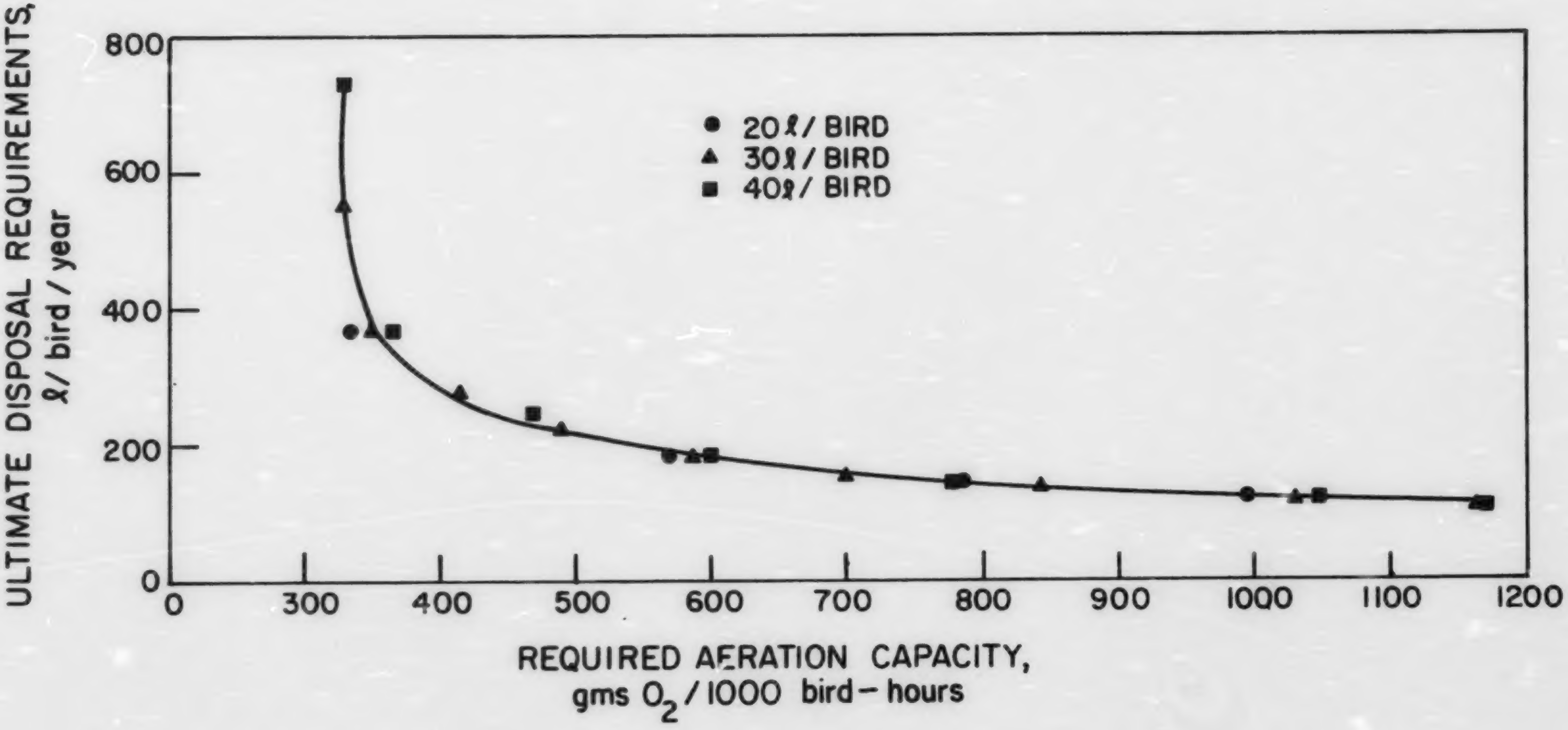

Figure 5.9. The relationships between ultimate disposal and aeration requirements in a continuously loaded, batch aeration system for poultry wastes.

ultimate disposal volume occurs. Since both fixed and operating costs increase as aeration capacity requirements increase, there is little apparent value in achieving a very low ultimate disposal volume.

In the design of a batch aeration system, factors such as storage and/or ultimate disposal requirements can not be considered independently. For effective system design, both factors must be considered in conjunction with aeration requirements. Although increasing system volume and the length of the batch cycle operating period increases storage capability and reduces ultimate disposal requirements, this may not provide an optimum design solution. Depending on the relative costs of aeration and ultimate disposal, it may be more desirable to select a batch cycle operating period which reduces aeration requirements and increases the stabilized waste volume. Where weather and/or other constraints limit ultimate disposal opportunities, additional non-aerated storage may provide the least cost system.

5.3.2 Continuous Flow Aeration System Design

The process design of a continuous flow aeration system for poultry wastes requires the identification of values for SRT and MLTS concentration compatible with waste management objectives. For the continuous flow mode of operation, SRT and MLTS concentration are independent process design variables. Both aeration and ultimate disposal requirements are dependent on these variables.

An advantage of the continuous flow as compared to the batch mode of aeration system operation is that SRT is an independent process design variable. Therefore, a desired level of waste stabilizaton consistent with overall waste management objectives can be achieved by selecting the appropriate SRT value. Relationships between SRT and removal efficiencies for the four major waste characterization parameters associated with poultry manure are presented in Figures 5.10 and 5.11. These relationships were derived from the process design equations, Equations 4.20 through 4.23. As SRT and therefore the degree of waste stabilization increases, carbonaceous and nitrogenous oxygen demands also increase (Figure 5.12).

With the exception of situations where a high degree of nitrogen removal is required due to limitations of available land for ultimate disposal, it appears that odor control will be the principal waste management objective for these systems. In these situations, a high degree of waste stabilization and thus a long SRT does not appear warranted. Decreasing SRT from 40 days to 10 days will reduce both carbonaceous and nitrogenous oxygen demands by 24 percent (Figure 5.12). These decreases can be translated into reduced fixed and operating costs for aeration.

A second advantage of the continuous flow versus batch mode of aeration system operation is the ability to maximize oxygen transfer efficiency by maintaining low MLTS concentrations. However, the absence of practical liquid-solid separation and solids thickening approaches for these wastes results in an increased volume of effluent requiring ultimate disposal as oxygen transfer efficiency is maximized. Thus, a trade-off also exists with a continuous flow system between aeration and ultimate disposal requirements.

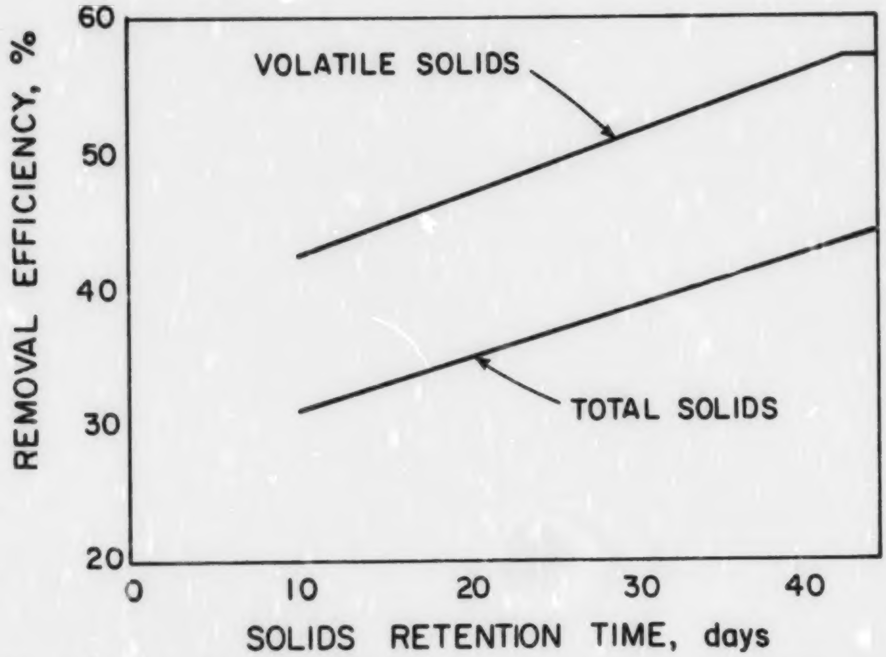

Figure 5.10. Design relationships between SRT and removal of total and volatile solids.

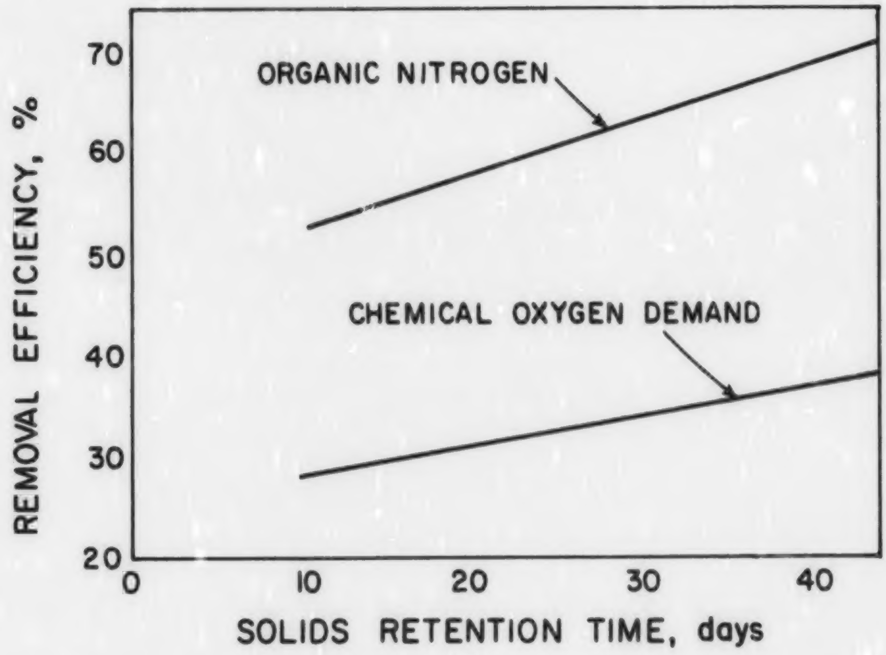

Figure 5.11. Design relationships between SRT and removal of organic nitrogen and COD.

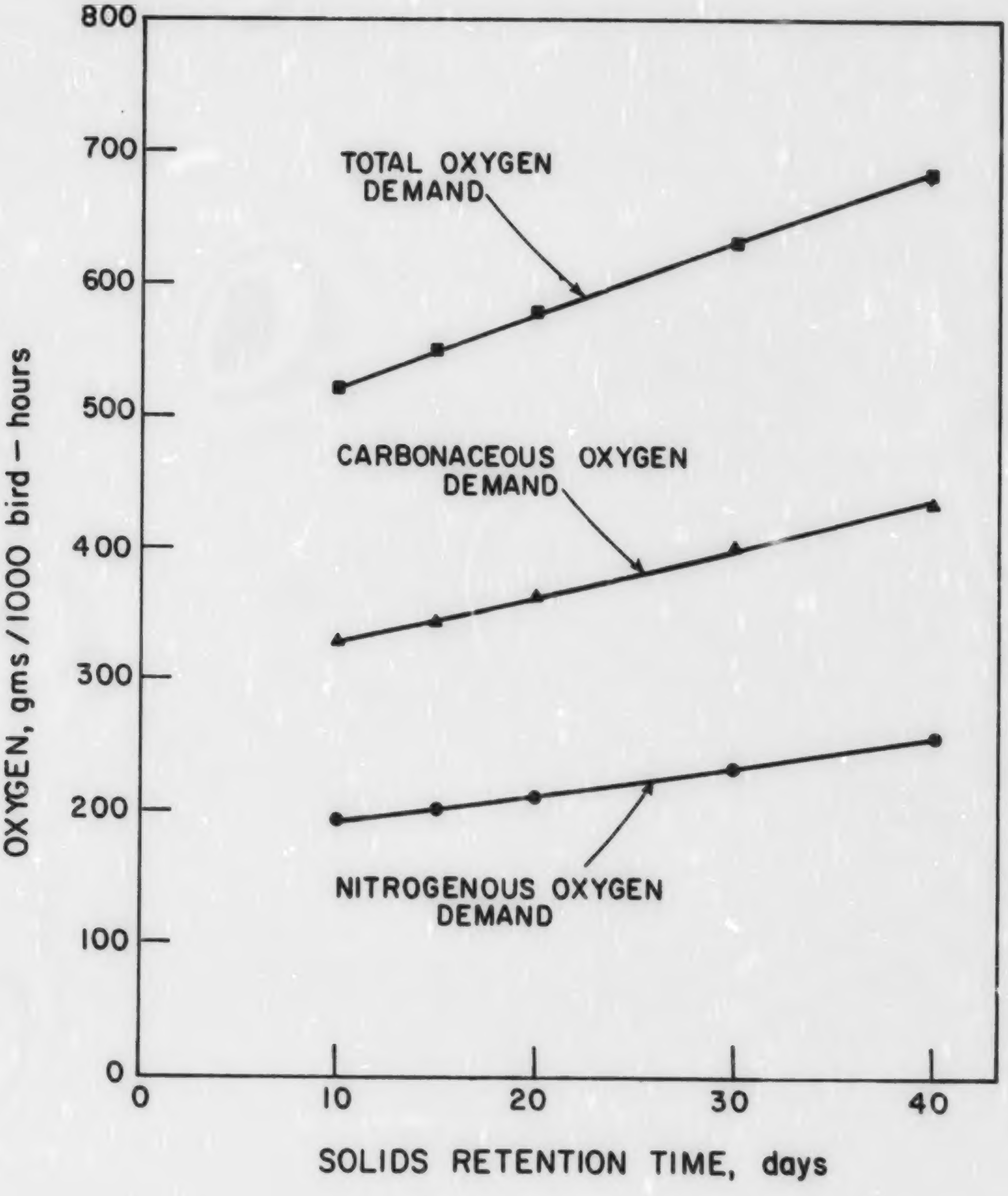

Figure 5.12. Design relationships between SRT and carbonaceous nitrogenous and total oxygen demands.

Representative changes in aeration requirements as a function of MLTS concentration for systems operated at 10 and 30 day SRTs are presented in Figure 5.13. Increasing design MLTS concentration up to 20 gm/ℓ does not increase aeration requirements which are necessary to meet the microbial oxygen demand. However, an increase from 20 gm/ℓ to 60 gm/ℓ produces an increase in aeration requirements of 151 percent.

In a continuous flow system, the volume of stabilized waste requiring ultimate disposal decreases as the equilibrium MLTS concentration increases. This relationship is illustrated in Figure 5.14. In order to identify an optimum design value for MLTS concentration in a continuous flow aeration system, it is necessary to analyse the trade-offs between aeration and ultimate disposal requirements. A plot of ultimate disposal versus aeration requirements for SRTs of 10 and 30 days (Figure 5.15) shows these relationships. A dependence on SRT exists at low MLTS concentrations but does not occur at higher MLTS concentrations. Figure 5.15 also illustrates that design below an ultimate disposal requirement of 200 ℓ/bird-year provides only moderate reductions in ultimate disposal volumes. However, aeration capacity requirements increase rapidly as will fixed and operating costs. Thus there is little apparent value in reducing ultimate disposal requirements to extremely low levels.

In a continuous flow system, system volume is a function of both SRT and MLTS concentration. The relationship between SRT and system volume per bird for MLTS concentrations of 20 gm/ℓ and 40 gm/ℓ are shown in Figure 5.16. The magnitude of increase of system volume with SRT is significantly greater at lower MLTS concentrations. Relationships between system volume per bird and MLTS concentration for SRT's of 10 and 30 days are presented in Figure 5.17.

In designing a continuous flow aeration system, decreasing SRT and/or increasing MLTS concentration will decrease system volume and associated capital costs. This will reduce mixing requirements and possibly alleviate problems due to sediment accumulations. In that increasing MLTS concentration beyond 20 gm/ℓ will increase aeration requirements (Figure 5.13), minimizing SRT, while still achieving odor control and stabilization, appears to have merit for reducing both system volume and aeration requirements (Figure 5.12).

In summary, the effective process design of a continuous flow aeration system for poultry wastes requires analysis of the relationships involving SRT and MLTS concentration with respect to aeration capacity, ultimate disposal requirements, and system volume. The relative costs of these factors should determine an optimum design, a least cost system.

5.3.3 Comparison of Batch versus Continuous Flow Modes of Operation

Comparison of the trade-offs between ultimate disposal and aeration capacity requirements for the batch and continuous flow modes of aeration system operation (Figures 5.9 and 5.15) indicates little difference in the characteristics of the two operational modes. Since it also appears that the storage aspect of a batch system is offset by increased aeration capacity requirements, differences in system volume per bird and additional storage facility requirements are also minimal. The continuous flow operational mode has the potential of minimizing aeration and ultimate disposal requirements. However,

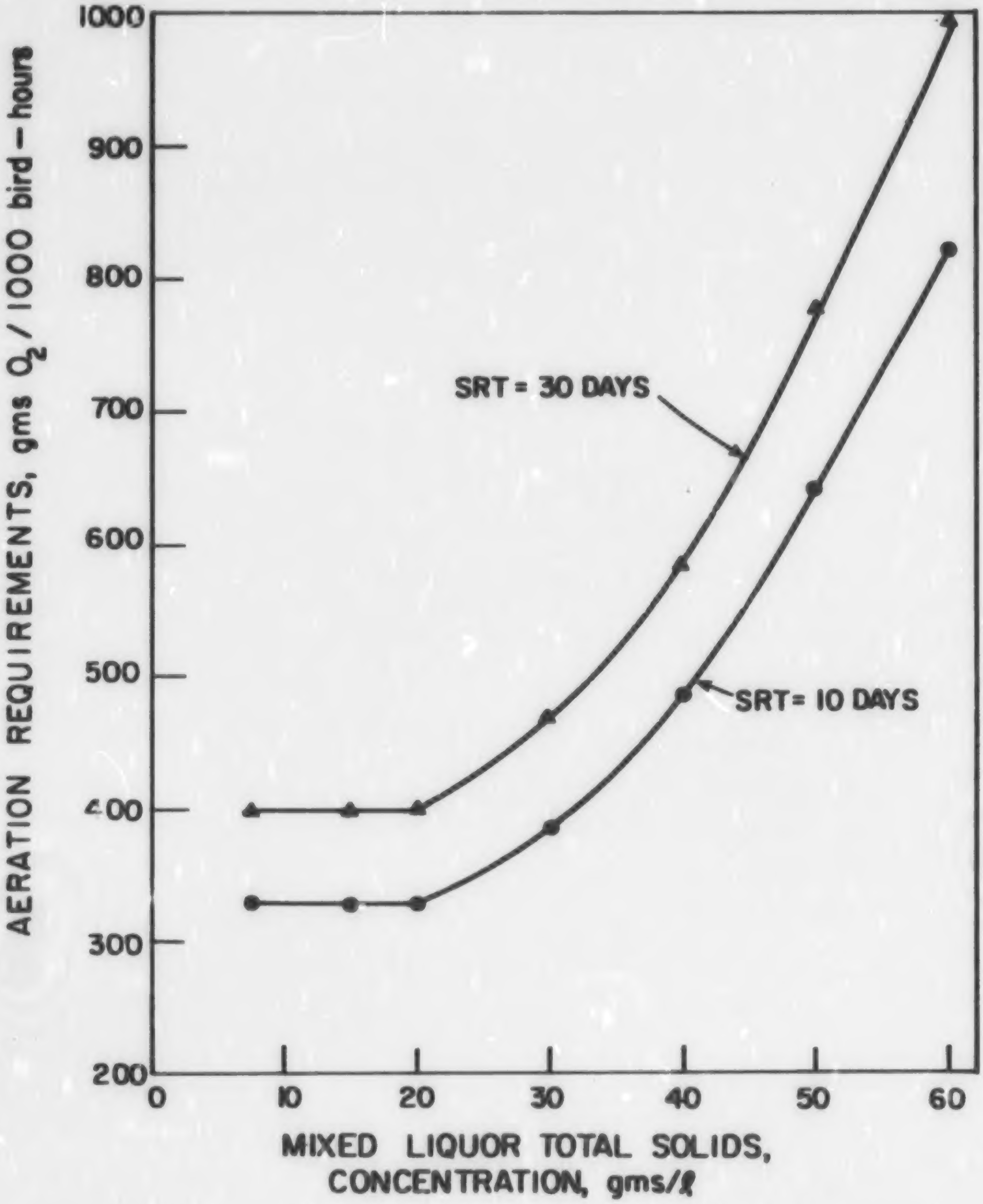

Figure 5.13. Aeration requirements as a function of MLTS concentration in continuous flow aeration systems.

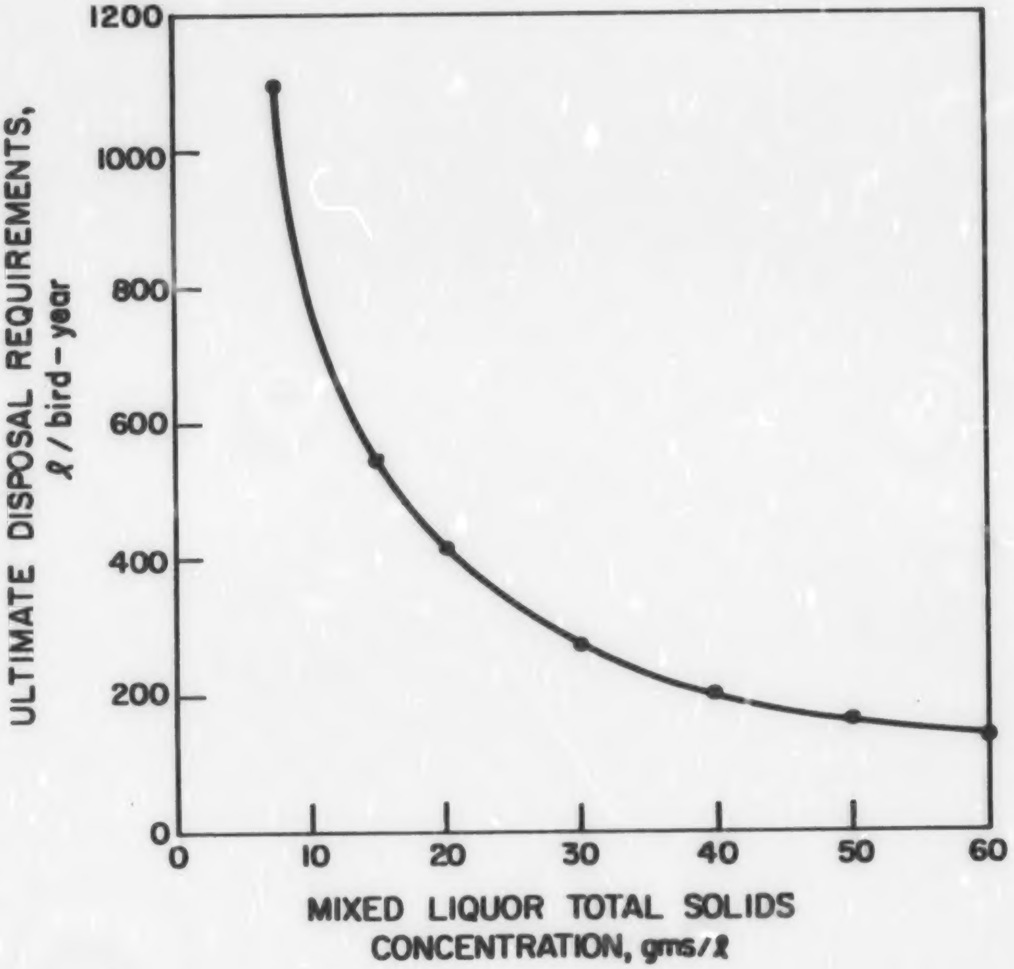

Figure 5.14. Ultimate disposal requirements as related to MLTS concentration in a continuous flow system.

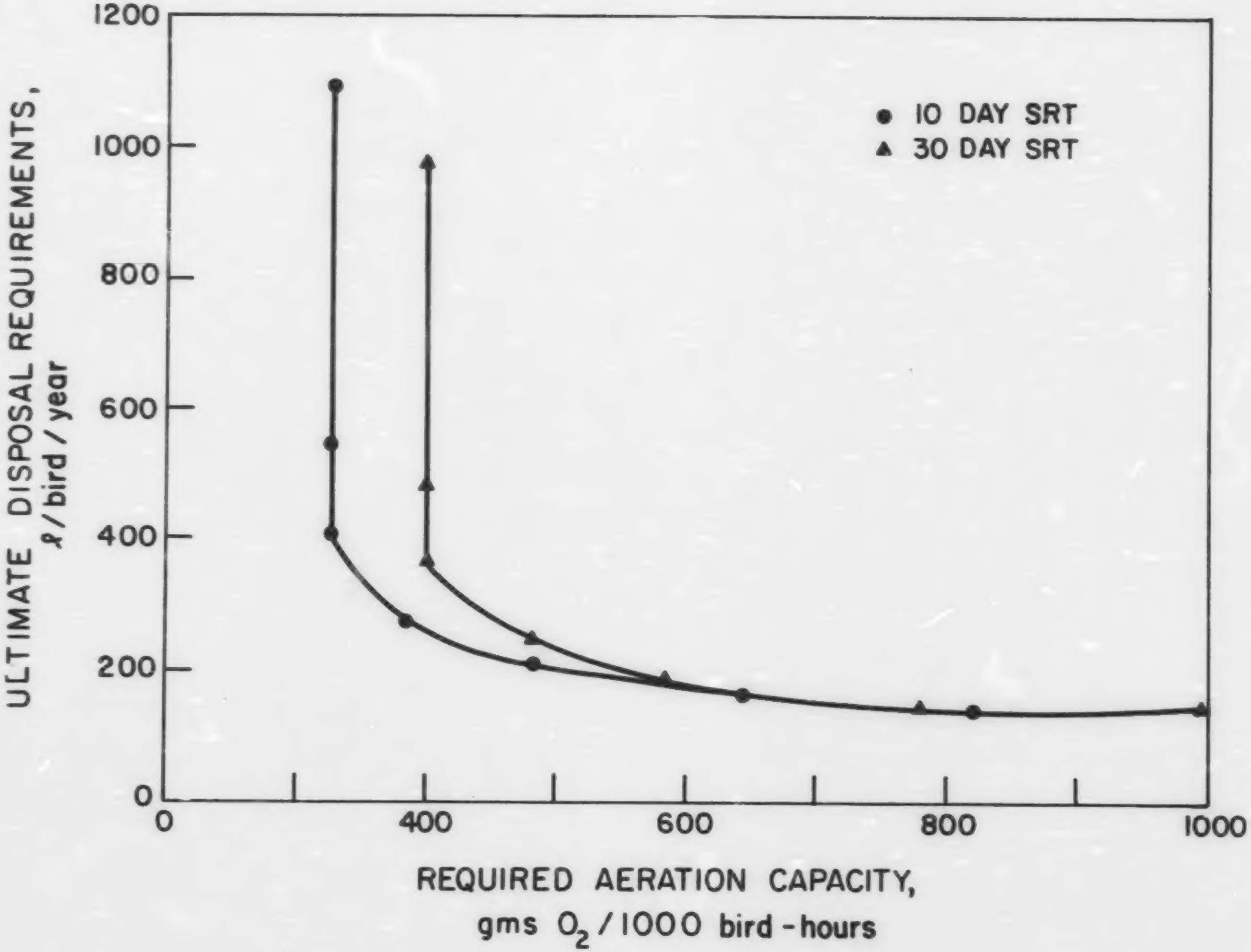

Figure 5.15. The relationship between ultimate disposal and aeration requirements in a continuous flow aeration system for poultry wastes.

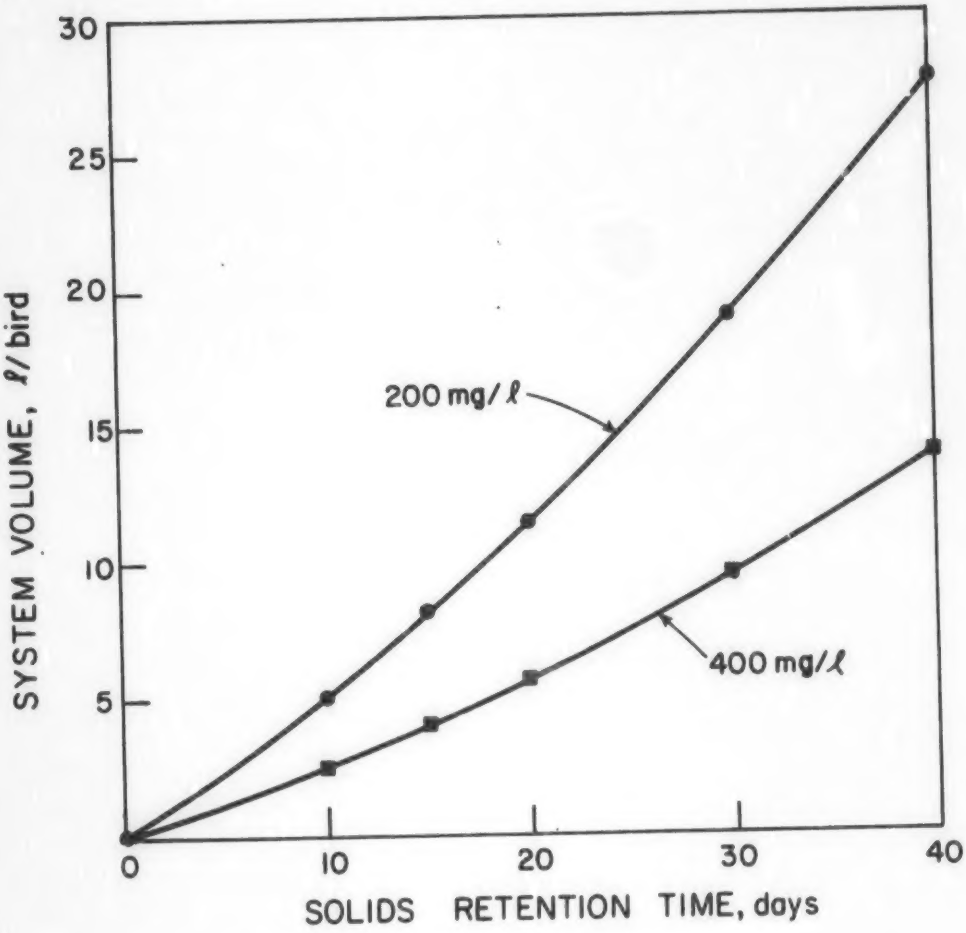

Figure 5.16. Design relationships between SRT and system volume for MLTS concentrations of 20 gm/ℓ and 40 gm/ℓ.

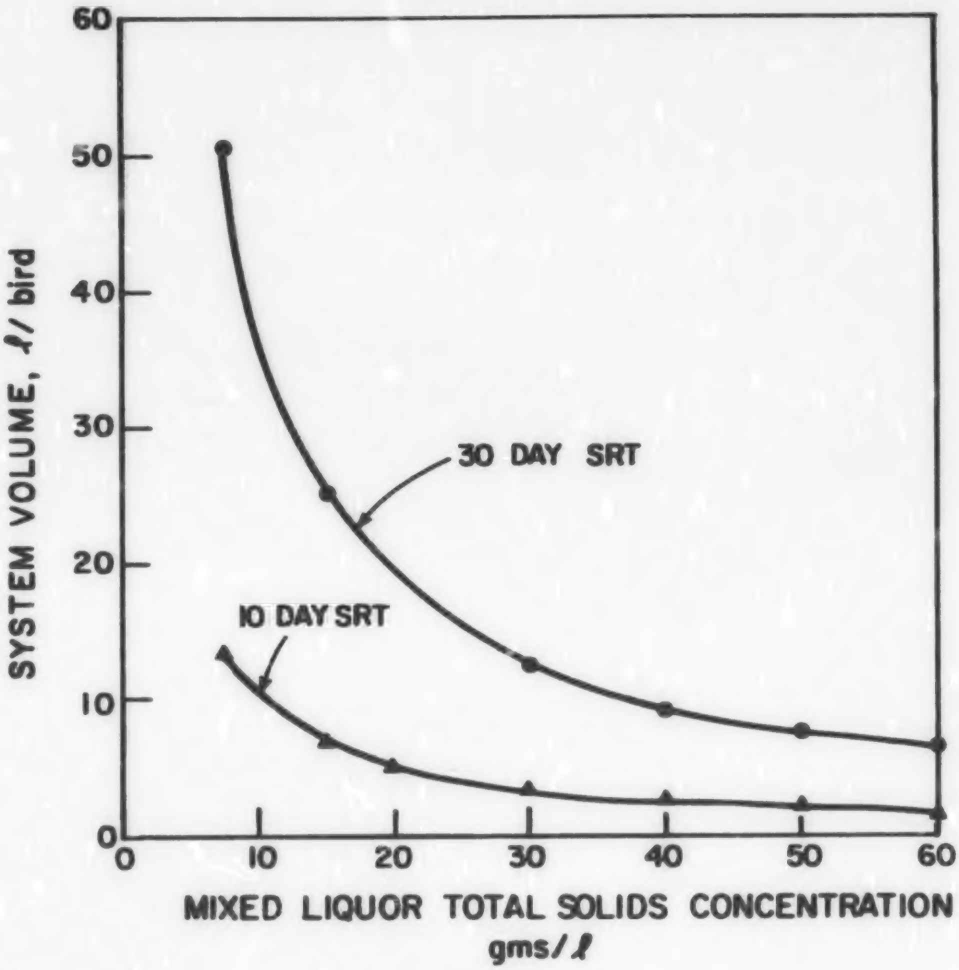

Figure 5.17 Design relationships between MLTS concentration and system volume for 10 day and 30 day SRT's.

this potential can only be realized when effective liquid-solids separation and solids thickening techniques are developed.

5.3.4 Computer Design Programs

The process design methodologies for both batch and continuous flow aeration systems (Chapter 4) have been incorporated into computer programs to assist design computations for specific situations. Flow diagrams and source listings for both programs are presented in the Appendix, Figures A-6 through A-9. The following is a brief discussion of user input and computed output for both programs.

For the batch system design program, the user must specify the following:

A. Fixed constant values for substrate removal relationships for poultry wastes (Table 4.4);

B. Raw waste characteristics expressing each parameter as gm/bird-day;

C. The number of birds for the system under consideration;

D. A selected value or range of values for system volume per bird, ℓ/bird;

E. A selected value or range of values for day of operation in a batch cycle, days.

For each specified value of system volume per bird, this program will compute the following design information for each day of operation:

A. The residual quantity, gm/bird-day, and the percent removal for each waste characterization parameter;

B. The mixed liquor total solids concentration, gm/ℓ;

C. Carbonaceous, nitrogenous, and total oxygen demands, gm O_2/hour;

D. Alpha;

E. Required aeration capacity to meet the carbonaceous, nitrogenous, and total oxygen demands, gm O_2/hour.

In order to utilize the continuous flow system design program, the user must specify the following:

A. Fixed constant values for substrate removal relationships for poultry wastes (Table 4.4);

B. Raw waste characteristics expressing each parameter as gm/bird-day;

C. The number of birds for the system under consideration;

D. A selected value or range of values for SRT;

E. A selected value or range of values for MLTS concentration.

For each specified value of SRT, this program will compute the following design information for each MLTS concentration:

A. The residual quantity, gm/bird-day, and the percent removal for each waste characterization parameter;

B. Carbonaceous, nitrogenous, and total oxygen demands, gm O_2/hour;

C. Alpha;

D. Required aeration capacity to meet the carbonaceous, nitrogenous, and total oxygen demands, gm O_2/hour;

E. System volume, ℓ;

F. Flowrate to maintain an equilibrium MLTS concentration, ℓ/day.

The computed flow rate value also represents ultimate disposal requirements in the absence of a liquid-solid separation process.

5.4 Referencs

1. Sobel, A.T. The High-Rise System of Manure Management. AWM 76-01. Dept. of Agricultural Engineering, Cornell University, Ithaca, New York. 1976. 45 p.

CHAPTER 6

SYSTEM COMPARISONS

6.1 Introduction

In terms of odor control and the reduction of water pollution potential, both high-rise, undercage drying and aeration systems represent feasible poultry waste management alternatives. However, due to differences such as location, specific waste management objectives, and overall management practices, neither system will be ideal for all situations. The objective of this chapter is to discuss the relative merits of each system and to provide economic projections which can serve as a basis for system selection for specific situations. Included will be odor control capability, plant nutrient value, and refeeding potential of the stabilized wastes for both systems.

6.2 Odor Control

With proper design and operation, both high-rise, undercage drying and aerobic biological stabilization systems are effective odor control techniques for poultry wastes. In addition, these waste management approaches have the capability of reducing gaseous ammonia concentrations within poultry houses. However, differences in both odor and gaseous ammonia control capabilities exist between these approaches.

Results of a pilot plant scale comparison of odor levels and poultry house atmospheric ammonia concentrations (Table 6.1) have shown that aeration can be a more effective odor and ammonia control technique.

TABLE 6.1. COMPARISON OF ODOR LEVELS AND POULTRY HOUSE ATMOSPHERIC AMMONIA CONCENTRATIONS FOR AERATION AND DRYING SYSTEMS (1)

System	Odor Level*	Gaseous Ammonia Concentration, mg/m^3
Oxidation Ditch	1.1	< 1
Forced Air, Undercage Drying	3.7	1-2

*Ranked on a scale of 0 to 10 with 10 equal to a very offensive odor.

A human panel was used in this study to evaluate the odor level generated by each system (2). Poultry manure collected and stored under uncontrolled anaerobic conditions was ranked near 8. Gaseous ammonia concentrations for each system were determined by scrubbing the ventilation air at the exhaust fans (3).

The aeration capacity of the oxidation ditch compared in Table 6.1 was adequate to meet both the carbonaceous and nitrogenous oxygen demands. Higher gaseous ammonia concentrations will occur when aeration capacity is sufficient to satisfy only the carbonaceous oxygen demand. However, a comparable level of odor control has been demonstrated at this level of oxygen transfer (4).

The drying system compared in Table 6.1 differed from the "typical" high-rise system in that long term storage was not provided. In addition, the average moisture content of the manure removed from this system; 45 percent, wet basis (WB); is below the reported average system moisture content of 63 percent, WB for a high-rise, undercage drying system (5). Thus, odor levels and atmospheric ammonia concentrations for high-rise, undercage drying systems may be slightly greater than those values reported in Table 6.1.

These results, along with other observations, suggest that an aeration system may be the preferable waste management alternative in situations where a high degree of odor control is necessary. If requirements are less stringent, the degree of odor control provided by high-rise, undercage drying may be sufficient.

6.3 Economic Comparison

A major factor in the decision to employ a particular waste management system will be the relative cost of each alternative. While cost information relative to the oxidation ditch and high-rise, undercage drying has not been totally lacking, available information has focused on operating costs. Moreover, differences in factors such as size of operation and level of technology development have made comparisons on an equal basis impossible. The objective of this section to present an analysis of the costs associated with comparable oxidation ditch and high-rise, undercage drying systems as well as labor requirements for ultimate disposal.

To provide an equal basis for an economic comparison, system designs based on respective design methodologies (Chapters 3 and 4) and the discussion of design approaches (Chapter 5) were developed. The rationale for this approach instead of basing cost analyses on existing systems was to eliminate differences such as number of birds, waste characteristics, and bird density which varies with type of cage system and number of birds per cage. Differences in these factors can indirectly effect waste management costs. Common criteria used in the design of both waste management systems for this comparison are summarized in Table 6.2. It was assumed that costs for cages, feeding equipment, ventilation fans, etc., would be equal for both waste management systems. Thus, these items were excluded from consideration since the costs of interest are those due to the different waste management systems.

TABLE 6.2. COMMON CRITERIA FOR OXIDATION DITCH AND HIGH-RISE DRYING SYSTEMS DESIGN

No. of Birds - 30,000

Type of Cage System - Full Stairstep, 4 Rows

Management Practices - 4 Birds per 31 cm x 46 cm (12 in. x 18 in.) cage

Building - 12.8 m x 152.4 m (42 ft x 500 ft)

Building Structural Design - Timber Column

6.3.1 Waste Management Systems Design

The primary design objective for each system was odor control with the degree of waste stabilization dependent on that factor. The following is a brief discussion of each waste management design.

6.3.1.1 High-Rise, Undercage Drying

Using suggested design values (Table 3.5), the average drying air velocity to provide odor control and permit handling of manure as a solid for the criteria presented in Table 6.2 was determined to be 0.78 m/sec (154 ft/min). Moisture production was assumed to be 100 gm H_2O/bird-day. A velocity of 0 78 m/sec requires drying air circulating fans with capacities of 9.4 m^3/sec (20,000 ft^3/min) spaced at 30 m (100 ft) intervals. A 1.2 m, 0.746 kw (48 in., 1.0 h.p.) fan will provide an airflow of 9.4 m^3/sec. For the 152 m (500 ft) building under consideration, a total of eight 0.746 kw fans would be required. To provide airflow in a racetrack shaped pattern (Figure 3.3), two 0.91 m, 0.373 kw (36 in., 0.5 h.p.) fans also would be necessary to provide cross airflow at each end of the building.

Based upon reported data (5), the anticipated quantity of dried manure from this system (30,000 birds) should be approximately 1315 m^3 (46,500 ft^3) per year. This is based on a density of 32 kg/m^3 (20 lb/ft^3). Density as accumulated should be higher but decreases due to handling.

As previously discussed (Chapter 3), high-rise, undercage drying necessitates the construction of a two story structure as opposed to a conventional single story poultry house. It also requires construction of a floor system to support the cages and to provide aisles between the cage rows. In this design, a concrete floor in the manure storage area was included to facilitate manure removal. Although many high-rise houses have been constructed with a compacted earthen or cinder base, experience indicates that the use of a concrete floor is desirable.

6.3.1.2 Undercage Oxidation Ditches

The aeration system for this cost analysis was designed as a batch system with a system volume of 30 ℓ/bird (8 gal./bird). The system was designed to provide 70 days storage with a maximum mixed liquor total solids (MLTS) concentration of 45 gm/ℓ. The carbonaceous oxygen demand for this system has a maximum estimated value of 415 gm O_2/1000 bird-hr or 12.45 kg O_2/hr for 30,000 hens. To meet this oxygen demand at a MLTS concentration of 45 gm/ℓ, an aeration capacity of 21 kg O_2/hr is necessary due to the decrease in oxygen transfer efficiency with an increase in MLTS concentration (Table 5.4). The volume of stabilized waste requiring ultimate disposal for this system will be 156 ℓ/bird or 4680 m^3(165,251 ft^3) per year.

6.3.2 Cost Analysis

Each waste management system was divided into four components to simplify cost analyses. They are facilities costs related to the waste management system, fixed and operating costs for stabilization equipment, and fixed costs for handling and disposal of manure. The capital component of annual fixed costs were determined using an amortization rate of 9% assuming a 20 year life for structural components and a 10 year life for equipment with no salvage value. Taxes and insurance were based on a rate of 3 1/2 % of the investment cost per year. Maintenance costs were assumed to be 1% and 2% of the respective investment costs for structural components and equipment. A value of $0.035 per kilowatt-hour was used for the cost of electrical power. Costs for equipment, such as aeration units, fans, and manure handling equipment, were obtained from manufacturers or their representatives.

6.3.2.1 Facilities Costs

Both oxidation ditches and high-rise, undercage dyring systems will increase poultry housing costs above that for a conventional cage type poultry house. These costs were included in the cost analysis for each waste management system. Since the high-rise drying system is an integral part of the structure, total structural costs for a conventional house with manure collection pits, undercage oxidation ditches, and a high-rise house were compared. Cost estimates for each, based upon the common criteria presented in Table 6.2, were obtained from the building department of Agway, Inc., a northeastern agricultural cooperative (6). Total structural costs for each building and the waste management component of the costs for oxidation ditches and high-rise drying are presented in Table 6.3. Based upon the waste management component of structural costs, annual facilities costs including capital costs, taxes and insurance, and repairs and maintenance for each alternative are presented in Table 6.4.

6.3.2.2 Stabilization Costs

In this analysis, stabilization costs were defined as the sum of fixed and operating costs associated with the operation of aeration units and drying air circulating fans. Analysis of fixed costs for oxidation ditch aeration units (Table 6.5), showed a wide variation between manufacturers. The same

TABLE 6.3. ESTIMATES OF THE WASTE MANAGEMENT COMPONENT OF STRUCTURAL COSTS FOR OXIDATION DITCHES AND HIGH-RISE DRYING SYSTEMS

	Structural Costs, $	Waste Management Component of Structural Costs, $
Conventional Poultry House with Manure Collection Pits	144,000	---
Conventional Poultry House with Oxidation Ditches	146,500	2,500
High-Rise Poultry House	172,500	28,500

phenomenon was observed in the estimation of operating costs in terms of cost per kg of oxygen transfer capacity (Table 6.5). These operating cost estimates were based on oxygen transfer capacities and power requirements obtained from reported research results or from manufacturer's brochures when independently developed data was not available.

Comparison of Tables 6.5 and 6.6 revealed that aeration units with high annual fixed costs had low operating costs. Expressing annual fixed costs in terms of cost per kg of oxygen transfer capacity and combining this value with operating costs revealed that there was little difference between 4 of the 5 units evaluated (Table 6.7). Excluding unit B, the average total cost per kg of oxygen transferred was \$0.058. For the aeration system under consideration with a maximum required oxygen transfer capacity of 21 kg O_2/hr, the total annual cost for oxygen transfer was estimated to be \$10,524.

As previously noted, the 30,000 bird high-rise system design requires eight 0.746 kw and two 0.373 kw drying air circulating fans. A study of air moving efficiencies of agricultural propeller type fans such as those used to circulate dyring air in a high-rise manure drying system has shown a wide variation in efficiency between manufacturers (7). Analysis of both annual fixed and operating costs were based on a maximum reported airflow efficiency of 0.010 m^3/sec per watt (21 ft^3/sec per watt). For the 10 fans required, the annual fixed cost was found to be \$749 per year based upon initial costs obtained from vendors. The annual operating cost was calculated to be \$2569 per year at \$0.035/kwhr.

6.3.2.3 Handling and Disposal Equipment Costs

The total cost for handling and disposal of manure is perhaps the most difficult component of total waste management costs to quantify due to the comparatively high labor component in comparison to other aspects of these waste management systems. Trade-offs exist between investment and other fixed costs

TABLE 6.4. ANNUAL WASTE MANAGEMENT FACILITIES COSTS FOR OXIDATION DITCHES AND HIGH-RISE DRYING FOR A 30,000 BIRD OPERATION

	Annual[*] Capital Cost, $	Taxes &[**] Insurance, $	Repairs[†] Maintenance, $	Annual Facilities Costs, $
Undercage Oxidation Ditches	274	10	3	287
High-Rise, Undercage Drying	3,125	109	31	3,265

[*] Amortized at 9 percent per year over an estimated useful life of 20 years.

[**] Estimated at the rate of 3.5 percent of initial cost per year.

[†] Estimated at the rate of 2 percent of initial cost per year.

TABLE 6.5. ESTIMATED ANNUAL FIXED COSTS FOR OXIDATION DITCH AERATION UNITS

Manufacturer	Initial Cost, $	Annual* Capital Cost, $	Taxes and** Insurance, $	Maintenance† and Repairs, $	Total Annual Fixed Cost, $
A - 1.8 m rotor	8,170	1,274	286	163	1,723
- 2.4 m rotor	8,550	1,333	299	171	1,803
B -	1,270	198	44	25	267
C - 1.8 m rotor	2,610	407	91	52	550
D - 3.0 m rotor	3,500	546	122	70	738

* Amortized at 9 percent per year over an estimated useful life of 10 years.

**Estimated at the rate of 3.5 percent of initial cost per year.

† Estimated at the rate of 2 percent of initial cost per year.

TABLE 6.6. ESTIMATED OPERATING COSTS FOR OXIDATION DITCH AERATION UNITS

Manufacturer	Capacity, gm O_2/hr	Power Requirements, kw*	gm O_2/ kw-hr	Cost/kg O_2, $**
A - 1.8 m rotor	4857	2.94	1652	.021
- 2.4 m rotor	6457	3.94	1644	.021
B -	1244	1.93	644	.105
C - 1.8 m rotor	3360	3.68	913	.040
D - 3.0 m rotor	3110	2.98	1044	.034

* Calculated from net power requirements assuming maximum motor efficiency of 75%.

**Based upon an electrical energy cost of $.035 per kw-hr.

TABLE 6.7. SUMMARY OF TOTAL COSTS FOR OXIDATION DITCH AERATION UNIT OXYGEN TRANSFER

Manufacturer	Operating* Cost/kg O_2, $	Annual Equipment Cost/kg O_2, $	Cost/kg O_2, $
A	.021	.040	.061
	.021	.032	.053
B	.105	.046	.151
C	.040	.019	.059
D	.034	.027	.061

*Based on 24 hour 360 day operation.

which are related to equipment capacities and operating and labor costs. In the interest of simplicity, only fixed costs for handling and disposal equipment were considered. Labor and operating costs were evaluated indirectly in terms of the number of loads of waste per year requiring ultimate disposal from each system.

A summary of the fixed manure handling and disposal equipment costs associated with each alternative is presented in Table 6.8. Also included are estimates of the number of loads of manure requiring ultimate disposal annually based upon anticipated waste volumes noted earlier and spreader capacities specified for each system.

TABLE 6.8. COMPARISON OF ANNUAL FIXED MANURE HANDLING AND DISPOSAL EQUIPMENT COSTS

	Oxidation Ditches, $	High-Rise Drying, $
Initial Cost	6,159*	4,915**
Annual Cost	960	766
Taxes & Insurance	216	172
Repairs & Maintenance	123	98
Total Annual Equipment Cost	1,299	1,036
No. of Loads per year	410	173

* 11.4 m^3 liquid manure spreader loaded by gravity.

**7.6 m^3 box type manure spreader and 75% of a tractor mounted front-end loader.

For the high-rise drying system, a skid steer or tractor mounted loader for manure removal from the building is necessary in addition to a box type manure spreader for transport and disposal. The costs in Table 6 reflect only fixed costs directly related to a front end loader. It was assumed that 75 percent of the annual operating time of the loader would be for manure handling. Since manure handling should represent only a small fraction of the annual tractor operating time, fixed costs associated with this tractor were omitted. For the oxidation ditches, it was assumed that the aerated slurry could be transferred to a manure spreader by gravity. Thus, only a closed, tank type liquid manure spreader was considered in the estimate of handling and disposal equipment costs for the oxidation ditch alternative.

6.3.2.4 Discussion

A summary of the component costs for the oxidation ditch and high-rise, undercage drying systems is presented in Table 6.9. These data show that managing poultry wastes using oxidation ditches operated as batch reactors will have a higher cost as compared to high-rise, undercage drying. This is in addition to higher ultimate disposal requirements (Table 6.8). However, it should be recognized that these liabilities are due primarily to the absence of effective liquid-solid separation and solids thickening techniques which would make operation of continuous flow aeration systems feasible. This would permit maintenance of MLTS concentrations of less than 20 gm/ℓ and reduce high stabilization costs due to the inefficiency of aerating poultry manure slurries at high MLTS concentrations.

TABLE 6.9. SUMMARY OF WASTE MANAGEMENT COMPONENT COSTS FOR OXIDATION DITCHES AND HIGH-RISE, UNDERCAGE DRYING

	Undercage Oxidation Ditches,$	High-Rise Undercage Drying, $
Facilities Costs	387	4,408
Stabilization Costs	10,524	3,318
Manure Handling and Disposal Equipment Costs	1,299	1,036
Total Annual Waste Management Costs	12,210	8,762

Both fixed and operating costs would be reduced due to the decrease in oxygen transfer capacity requirements. A 50 percent reduction of stabilization costs would be possible. However, this alternative awaits the development of a practical liquid-solids separation process. Otherwise, the reduction in stabilization cost will merely be shifted into ultimate disposal costs.

A summary of the unit costs for the two alternative modes of oxidation ditch operation and for high-rise, undercage drying is presented in Table 6.10. The costs for the continuous flow mode of oxidation ditch operation do not include liquid-solid separation costs. Thus, actual costs for the continuous flow mode of operation with liquid-solids separation will be somewhat higher due to added fixed and operating costs for this process. However, the potential exists to reduce ultimate disposal costs if thickening to solids concentrations in excess of 45 gm/ℓ can be achieved. This would serve to reduce the high volumetric ultimate disposal requirements which is a major liability of this waste management approach.

TABLE 6.10. COMPARISON OF POULTRY WASTE MANAGEMENT UNIT COSTS*

System	Cost/1000 Hens/yr, $	Cost/Dozen Eggs,** $
Oxidation Ditch		
Batch	407	0.020
Continuous Flow †	211	0.010
High-Rise, Undercage Drying	292	0.0146

* Excludes labor and operating costs for ultimate waste disposal.

**Assumes 20 dozen eggs per hen-year.

† Excludes liquid-solid separation and thickening costs.

While the costs of both high-rise, undercage drying and aeration of poultry wastes are comparable, the practicality of these approaches will depend heavily on economic impact. Since the price the producer receives for eggs is determined by the market forces of supply and demand, there is no opportunity to pass on the cost of pollution control measures. The economic impact of any waste management system on net income is a logical criteria for the economic assessment of that system.

A 1975 survey (8) of New York State poultry farms showed that labor and management incomes varied widely. Income ranged from minus values to over $30,000 per operator. Similar variations were reported in 1974 and 1973 10). Differences in management skills among producers appear to be the major factor responsible for this variability.

As an alternative, capital investment and production costs were used as baselines for economic assessment of these waste management alternatives. This procedure permitted evaluation of economic impact in terms of efficient production resulting from skillfull management. Egg production costs in New York State for the years 1973-75 are presented in Table 6.11. The values noted are average values reported for New York State except for feed costs. Feed costs were based on 1.91 kg (4.2 lb) of feed per dozen eggs and 20 dozen eggs marketed per hen-year. The effect of good management is reflected in the noted feed conversion efficiency and production values which are above average.

The impact of waste management costs for high-rise, undercage drying and aeration systems on egg production costs for the years 1973-75 are summarized in Table 6.12. These results indicate that both approaches are economically feasible. In considering the costs presented in this section, it should be recognized that these values are for specific system designs. For example, increasing the cumulative time of batch aeration system operation will reduce ultimate disposal requirements but increase stabilization costs. Thus,

TABLE 6.11. NEW YORK STATE EGG PRODUCTION COSTS (8, 9, 10)

Cost/Hen-Year ($)	1975	1974	1973
Return to Capital @ 9%	0.67	0.69	0.67
Labor*	1.17	0.94	0.94
Feed†	5.56	5.73	5.12
Hen**	2.00	2.00	2.00
Building repairs	0.02	0.03	0.03
Electricity	0.11	0.10	0.11
Taxes	0.08	0.07	0.07
Insurance	0.09	0.11	0.11
Total	9.70	9.67	9.05
Production Cost/dozen eggs*†	0.485	0.484	0.453

* Includes Operator's Labor.

† Based upon 1.91 kg (4.2 lb) of feed/dozen eggs produced.

**Estimated cost of $2.25/bird less salvage value of $0.25/bird.

*† Based upon 20 dozen eggs/bird-year.

TABLE 6.12. IMPACT OF WASTE MANAGEMENT ALTERNATIVES ON EGG PRODUCTION COSTS

System	Percentage Increase In Egg Production Costs 1975	1974	1973
Oxidation Ditch			
Batch	4.1	4.1	4.4
Continuous Flow	2.1	2.1	2.2
High-Rise, Undercage Drying	3.0	3.0	3.2

relative costs can not be considered constant but will vary to some degree with variation in design.

6.4 Plant Nutrient Value

Poultry manure as produced contains nitrogen, phosphorus, and potassium as well as calcium in significant quantities. In situations where plant nutrients can be utilized for field crop production or marketed, the ability of a waste management system to conserve these nutrients is an import consideration. However, it should be recognized that the value of these nutrients is only realized when these nutrients are actually utilized in place of purchased fertilizer inputs. In situations where cropping activities are absent, conserved plant nutrients have no value unless a market exists. Then, the real value may be less than equivalent cost as chemical fertilizer due to a different supply and demand relationship.

Neither high-rise, undercage drying systems nor oxidation ditches operated for odor control appear to be effective systems for nitrogen conservation. A nitrogen loss of 53 percent based on mass balance results from a full scale high-rise, undercage drying system evaluation has been reported (5). The percentage of nitrogen remaining as ammonia was 37.5 percent. Since opportunities for volatilization during and following surface spreading are sizable, the potential for plant utilization of this ammonical nitrogen appears minimal. Thus, an assumption of a 71 percent nitrogen loss appears reasonable. This value compares favorably with the value of 69 percent for the biodegradable fraction of the nitrogen in poultry manure (Chapter 4).

In a study of the relationship between drying rates and nitrogen losses from poultry wastes, it was observed that the microbial activity responsible for the transformation of organic nitrogen to ammonia is not restricted until moisture levels are as low as 20 to 30 percent, wet basis (11). The magnitude of nitrogen loss was shown to be a function of the drying time to reach the equilibrium moisture content for poultry wastes, 10 to 15 percent wet basis. The following empirical relationship relating nitrogen loss to drying time was developed from laboratory studies.

$$NL = 77\left[1 - e^{-0.0032(DT) + 0.082}\right] \tag{6.1}$$

where: NL = nitrogen loss, %

DT = drying time to the equilibrium moisture content (10 to 15 % wet basis), hours.

In that rapid moisture reduction to low levels is necessary to conserve nitrogen contained in poultry wastes, high-rise, undercage drying does not appear to be an effective approach for the conservation of this plant nutrient.

A comparable magnitude of nitrogen loss has also been observed in oxidation ditches where aeration was limited to odor control requirements (4). Where levels of oxygen transfer are limited to the exerted carbonaceous oxygen demand, nitrification will be inhibited and nitrogen losses via ammonia desorption will occur. Increasing oxygen transfer to include the nitrogenous oxygen demand will permit nitrification and minimize nitrogen losses via ammonia stripping. However, results of pilot plant studies (12) have shown that a 30 percent loss of nitrogen via denitrification can occur even at high dissolved oxygen concentrations. Considering the refractory fraction of poultry manure organic nitrogen, the maximum level of conservation appears to be 39 percent of the quantity excreted. An analysis of the cost per unit nitrogen conserved based upon increased oxygen requirements to satisfy the nitrogenous oxygen demand, the Appendix, Figure A-10, indicates the minimum cost would be \$0.47/kg N(\$0.21/lb N). Decreased oxygen transfer efficiencies at mixed liquor total solids concentrations exceeding 20 gm/ℓ would increase these costs. At current prices of \$0.47/kg N (\$0.20 lb N) (13), this approach does not appear to be cost effective. In addition, storage under non-aerated conditions will result in dentirification due to the availability of organic carbon compounds even in highly stabilized slurries (14).

The transformations of phosphorus and potassium as well as calcium in either system have not been clearly delineated. Since these elements do not possess volatile forms, losses should not occur. Possible chemical transformations rendering these elements unavailable to plants should be equal in both systems. Thus, it appears that from a practical standpoint, the plant nutrient value of manure from high-rise, undercage drying systems and oxidation ditches are equal. However, it should be noted that both high-rise, undercage drying and aeration make poultry manure a more acceptable source of plant nutrients as compared to these wastes in an unstabilized form. This is due primarily to the reduction of malodors normally associated with these wastes.

Experience indicates that aerated poultry manure can be successfully marketed as a source of plant nutrients and as a soil conditioner to producers of vegetable and field crops (15). This material was sold for an average of \$2.60/1000 ℓ (\$10.00/gal.) over marketing costs thereby reducing overall waste management costs. An important aspect of this marketing venture was the acceptance of this material as a supplement to chemical fertilizer with farmers repeating purchases for a second year. Although undocumented, a similar market potential appears to exist for poultry manure from high-rise, undercage drying systems. It is important to understand that this approach to ultimate disposal depends on local demand and may vary greatly.

6.5 Refeeding Potential

The recovery of the nutrient value of poultry wastes through refeeding back to laying hens or to other animal species offers the potential of increased efficiency in the production of animal products. It is clear that from a nutritional standpoint the ruminants are the most desirable target species. This is due to their ability to utilize nonprotein nitrogen. However, the logistics of this practice are often undesirable.

Several studies have investigated the potential of refeeding both dried and aerated poultry wastes to laying hens. Flegal and Zindel (16) have reported a 3 percent increase in egg production with a diet containing 10 percent dried poultry manure. At higher levels, egg production was decreased as compared to the control diet. Nesheim (17) reported slightly lower egg production when dried poultry manure was fed at a level of 22.5 percent. The economic value of dried poultry manure was due primarily to its high phosphorus content. This factor along with associated amino acid and energy content made dried poultry manure a preferred source of phosphorus in comparison to meat meal and dicalcium phosphate. A 2 percent increase in egg production has been reported when aerated poultry manure was refed as a substitute for tapwater (18). No adverse effects were observed in relation to egg quality or bird health.

In order to refeed poultry wastes from a high-rise, undercage drying system, additional drying would be necessary. Moisture levels far below those typical of this drying approach are necessary to permit incorporation into a typical laying ration and to allow storage without spoilage. A machine type drier and feed mixing equipment would be required. Thus, the compatability of direct refeeding with high-rise, undercage drying of poultry wastes appears questionable. From a practical standpoint, the direct refeeding of aerated poultry wastes appears to have greater potential. Using the approach of substitution for tapwater, only a small pump for circulation and a trough type watering system would be required.

A number of unknown factors remain in the area of refeeding poultry wastes to laying hens. Thus, the question of refeeding potential should play a very minor role at present in the selection of a waste management system at this time.

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```
C     HIGH-RISE, UNDERCAGE DRYING: SENSITIVITY ANALYSIS OF
C     DESIGN VARIABLES
C     AF=AREA FACTOR, DIMENSIONLESS
C     MLF=MOISTURE LOADING FACTOR,KG H2O/M2-DAY
C     AV= AIR VELOCITY, M/SEC
C     VPD= VAPOR PRESSURE DIFFERENTIAL, PASCALS
C     X=FACTOR
C     MTDB=MANURIAL SURFACE MOISTURE CONTENT AT TIME T,DRY BASIS
C     MTWB=MANURIAL SURFACE MOISTURE CONTENT AT TIME T, WET BASIS
      REAL AF,MLF,AV,VPD,X,MTDB,MTWB
C     VARIABLE, AREA FACTOR,0.9-1.6
   10 READ,MLF,AV,VPD
      WRITE(6,11)
   11 FORMAT('1',40X,'AREA FACTOR RANGE = 0.9 TO 1.6')
      WRITE(6,12)
   12 FORMAT(' ',40X,'MOISTURE LOADING FACTOR = 2.72 KG H2O/M2-DAY')
      WRITE(6,13)
   13 FORMAT(' ',40X,'AIR VELOCITY = 0.5 M/SEC')
      WRITE(6,14)
   14 FORMAT(' ',40X,'VAPOR PRESSURE DIFFERENTIAL = 1360 PASCALS')
      WRITE(6,15)
   15 FORMAT(' ',47X,'AF',7X,'X',7X,'MTDB',7X,'MTWB')
   16 READ,AF
      IF(AF.EQ.-1) GO TO 20
      CALL CALC(X,AF,MLF,AV,VPD,MTDB,MTWB)
      WRITE(6,18) AF,X,MTDB,MTWB
   18 FORMAT(' ',40X,4F10.3)
      GO TO 16
C     VARIABLE, MOISTURE LOADING FACTOR,2.36-1.76,3.9-2.9
   20 READ,AF,AV,VPD
      WRITE(6,21)
```

Figure A-1. High-rise, undercage drying: sensitivity analysis of design variables - source listing and data output

```
   21 FORMAT(' ',40X,'MOISTURE LOADING FACTOR RANGE 3.70 TO 4.36 AND 2.2
     *2 TO 2.62 KG H2O/M2-DAY')
      WRITE(6,22)
   22 FORMAT(' ',40X,'AREA FACTOR = 1.3')
      WRITE(6,23)
   23 FORMAT(' ',40X,'AIR VELOCITY = 0.5 M/SEC')
      WRITE(6,24)
   24 FORMAT(' ',40X,'VAPOR PRESSURE DIFFERENTIAL = 1360 PASCALS')
      WRITE(6,25)
   25 FORMAT(' ',46X,'MLF',7X,'X',7X,'MTDB',7X,'MTWB')
   26 READ,MLF
      IF(MLF.EQ.-1) GO TO 30
      CALL CALC(X,AF,MLF,AV,VPD,MTDB,MTWB)
      WRITE(6,28) MLF,X,MTDB,MTWB
   28 FORMAT(' ',40X,4F10.3)
      GO TO 26
C     VARIABLE, AIR VELOCITY, 900-5400
   30 READ,AF,MLF,VPD
      WRITE(6,31)
   31 FORMAT(' ',40X,'AIR VELOCITY RANGE = .01 TO 2.0 M/SEC')
      WRITE(6,32)
   32 FORMAT(' ',40X,'AREA FACTOR = 1.3')
      WRITE(6,33)
   33 FORMAT(' ',40X,'MOISTURE LOADING FACTOR = 2.72 KG H2O/M2-DAY')
      WRITE(6,34)
   34 FORMAT(' ',40X,'VAPOR PRESSURE DIFFERENTIAL = 1360 PASCALS')
      WRITE(6,35)
   35 FORMAT(' ',47X,'AV',7X,'X',7X,'MTDB',7X,'MTWB')
   36 READ,AV
      IF(AV.EQ.-1) GO TO 40
      CALL CALC(X,AF,MLF,AV,VPD,MTDB,MTWB)
      WRITE(6,38) AV,X,MTDB,MTWB
   38 FORMAT(' ',40X,4F10.3)
```

Figure A-1. (Continued)

```
      GO TO 36
C     VARIABLE, VAPOR PRESSURE DIFFERENTAL, 340-2720
   40 READ,AF,MLF,AV
      WRITE(6,41)
   41 FORMAT(' ',40X,'VAPOR PRESSURE DIFFERENTIAL RANGE = 100 TO 2700 PA
     *SCALS')
      WRITE(6,42)
   42 FORMAT(' ',40X,'AREA FACTOR = 1.3')
      WRITE(6,43)
   43 FORMAT(' ',40X,'MOISTURE LOADING FACTOR = 2.72 KG H2O/M2-DAY')
      WRITE(6,44)
   44 FORMAT(' ',40X,'AIR VELOCITY = 0.5 M/SEC')
      WRITE(6,45)
   45 FORMAT(' ',45X,'VPD',8X,'X',7X,'MTDB',7X,'MTWB')
   46 READ,VPD
      IF(VPD.EQ.-1) GO TO 50
      CALL CALC(X,AF,MLF,AV,VPD,MTDB,MTWB)
      WRITE(6,48) VPD,X,MTDB,MTWB
   48 FORMAT(' ',40X,4F10.3)
      GO TO 46
   50 STOP
      END


      SUBROUTINE CALC(X,AF,MLF,AV,VPD,MTDB,MTWB)
      REAL X,AF,MLF,AV,VPD,MTDB,MTWB
      X=(AF/MLF)*AV*VPD
      MTDB=2271*(X**(-.494))
      MTWB=100*MTDB/(100+MTDB)
      RETURN
      END
```

Figure A-1. (Continued)

```
AREA FACTOR RANGE = 0.9 TO 1.6
MOISTURE LOADING FACTOR = 2.72 KG H2O/M2-DAY
AIR VELOCITY = 0.5 M/SEC
VAPOR PRESSURE DIFFERENTIAL = 1360 PASCALS
       AF          X          MTDB          MTWB
     0.900     225.000     156.401       60.999
     1.000     250.000     148.469       59.753
     1.100     275.000     141.640       58.616
     1.200     300.000     135.681       57.570
     1.300     325.000     130.421       56.601
     1.400     350.000     125.733       55.700
     1.500     375.000     121.519       54.857
     1.600     400.000     117.706       54.067


MOISTURE LOADING FACTOR RANGE 3.70 TO 4.36
AND 2.22 TO 2.62 KG H2O/M2-DAY
 AREA FACTOR = 1.3
 AIR VELOCITY = 0.5 M/SEC
VAPOR PRESSURE DIFFERENTIAL = 1360 PASCALS
      MLF          X          MTDB          MTWB
     4.360     202.752     164.655       62.215
     4.250     208.000     162.590       61.918
     4.140     213.527     160.497       61.612
     4.030     219.355     158.376       61.297
     3.920     225.510     156.226       60.972
     3.810     232.021     154.045       60.637
     3.700     238.919     151.831       60.291
     2.620     337.405     128.030       56.146
     2.520     350.793     125.592       55.672
     2.420     365.289     123.105       55.178
     2.320     381.034     120.565       54.662
     2.220     398.198     117.969       54.122
```

Figure A-1. (Continued)

```
AIR VELOCITY RANGE = .01 TO 2.0 M/SEC
AREA FACTOR = 1.3
MOISTURE LOADING FACTOR = 2.72 KG H2O/M2-DAY
VAPOR PRESSURE DIFFERENTIAL = 1360 PASCALS
      AV          X         MTDB       MTWB
    0.010       6.500     900.820     90.008
    0.250     162.500     183.677     64.749
    0.500     325.000     130.421     56.601
    0.750     487.500     106.747     51.632
    1.000     650.000      92.606     48.080
    2.000    1300.000      65.755     39.670


VAPOR PRESSURE DIFFERENTIAL RANGE = 100 TO 2700 PASCALS
AREA FACTOR = 1.3
MOISTURE LOADING FACTOR = 2.72 KG H2O/M2-DAY
AIR VELOCITY = 0.5 M/SEC
     VPD          X         MTDB       MTWB
   100.000     23.897     473.494     82.563
   340.000     81.250     258.681     72.120
   680.000    162.500     183.677     64.749
  1020.000    243.750     150.337     60.054
  1360.000    325.000     130.421     56.601
  1700.000    406.250     116.808     53.876
  2040.000    487.500     106.747     51.632
  2380.000    568.750      98.920     49.729
  2720.000    650.000      92.606     48.080
```

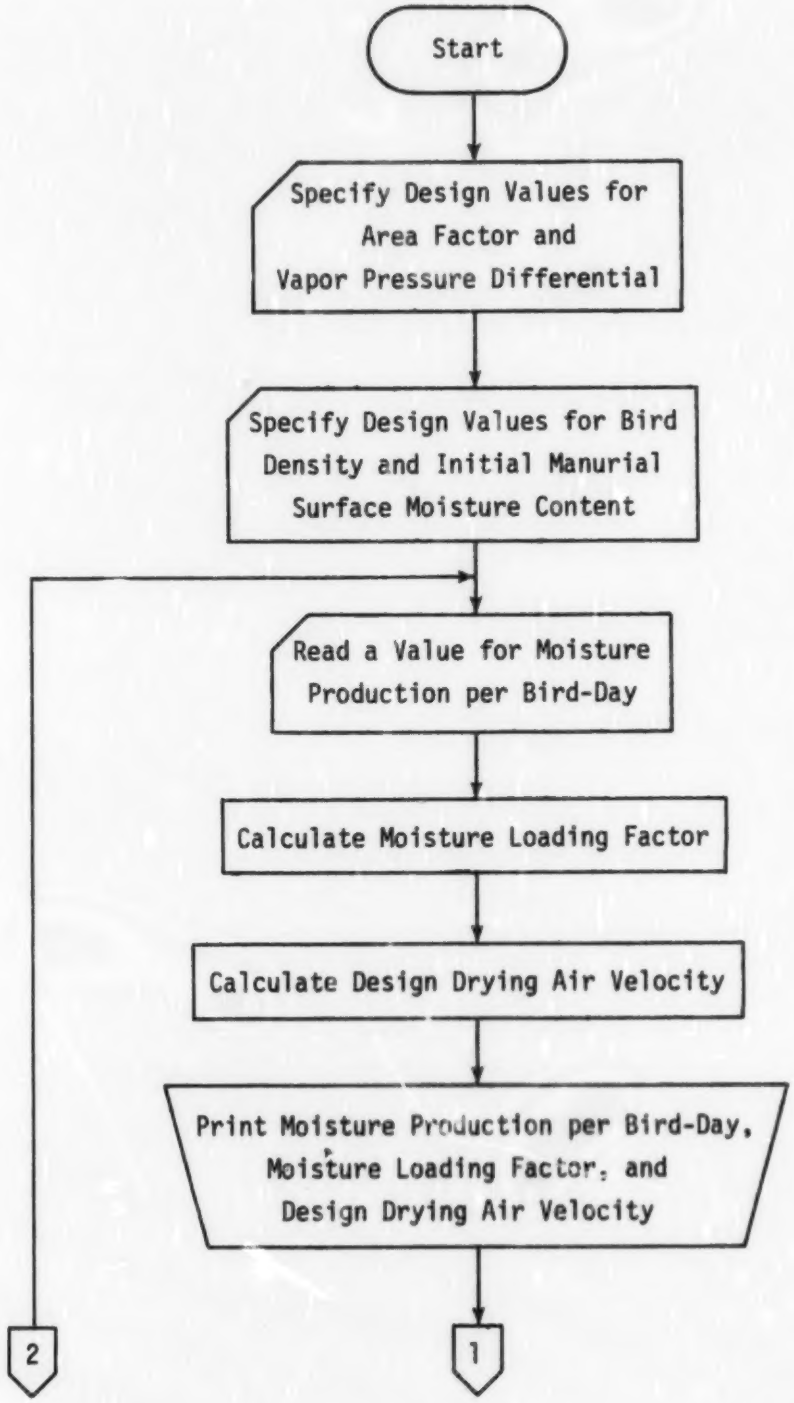
Figure A-1. (Continued)

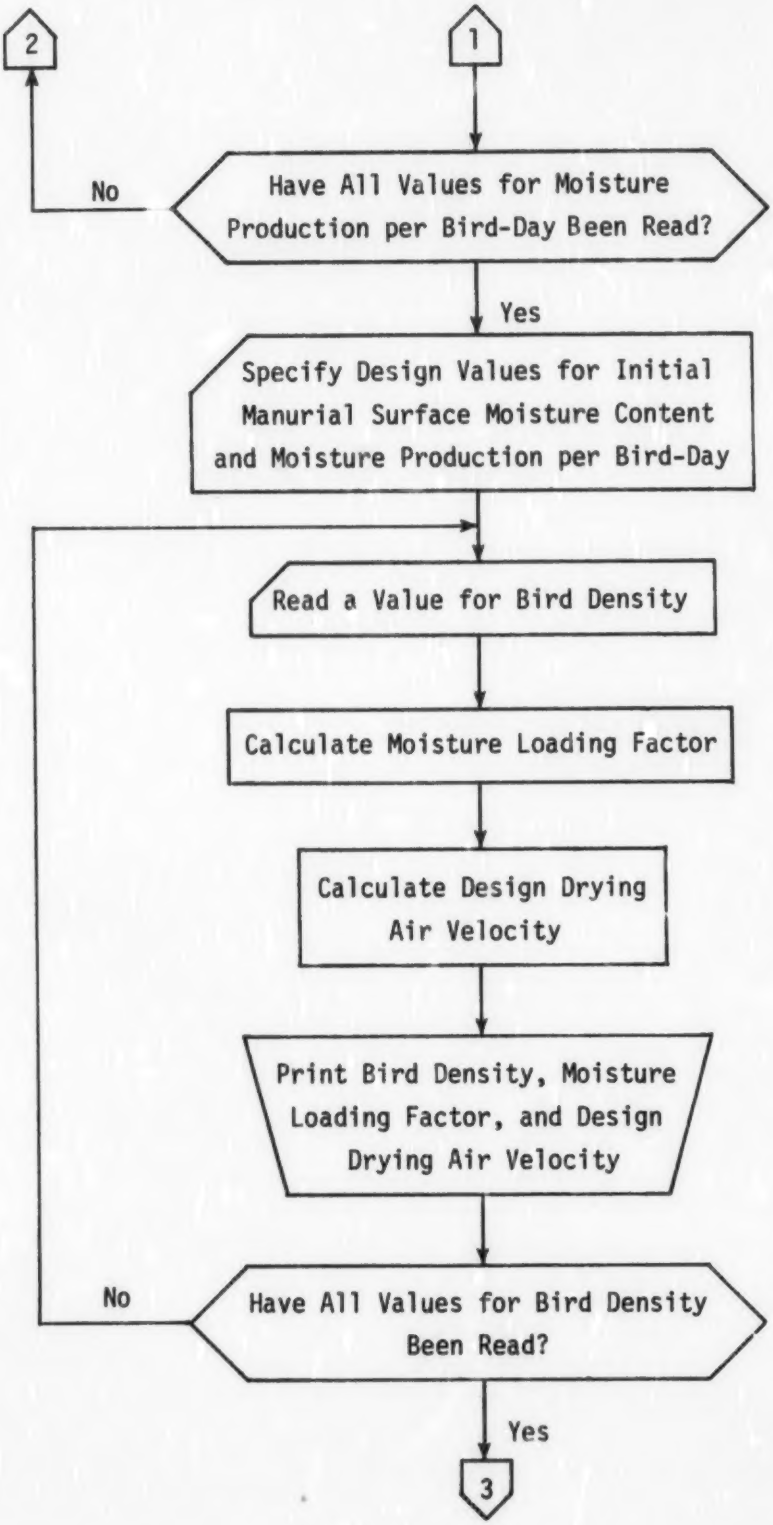
TABLE A-1. DATA USED FOR DETERMINATIONS OF REFRACTORY AND BIODEGRADABLE FRACTIONS OF POULTRY MANURE

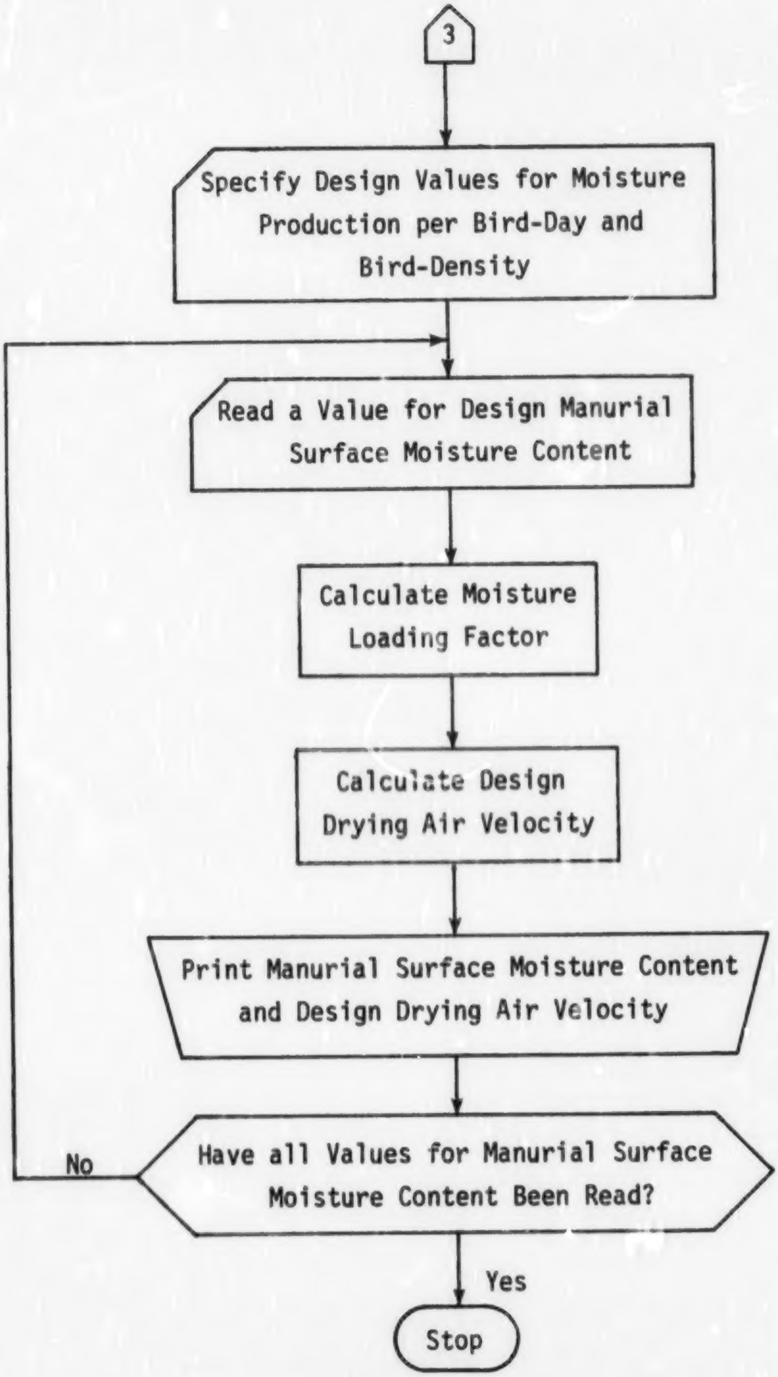
Parameter	SRT,* Days	S_0, gm/gm FS**	S_1, gm/gm FS**	S_1/S_0	$1/(S_0 \cdot SRT)$
Total Solids	10.5	3.45	2.54	0.74	0.028
	15	3.95	2.41	0.61	0.017
	18	3.45	2.31	0.67	0.016
	21	3.95	2.45	0.62	0.012
	27	3.95	2.55	0.64	0.009
	36.5	3.95	2.34	0.59	0.007
Volatile Solids	10.5	2.45	1.53	0.62	0.039
	15	2.95	1.45	0.49	0.022
	18	2.45	1.31	0.53	0.023
	21	2.95	1.50	0.51	0.016
	27	2.95	1.54	0.52	0.012
	36.5	2.95	1.35	0.46	0.009
Chemical Oxygen Demand	10.5	2.55	1.98	0.78	0.037
	15	2.56	1.72	0.67	0.026
	18	2.55	1.63	0.64	0.022
	21	2.56	1.76	0.69	0.019
	27	2.56	1.76	0.69	0.014
	36.5	2.56	1.66	0.65	0.011
Organic Nitrogen	10.5	0.262	0.134	0.51	0.364
	15	0.307	0.138	0.45	0.217
	18	0.262	0.109	0.42	0.212
	21	0.307	0.122	0.40	0.155
	27	0.307	0.108	0.35	0.121
	36.5	0.307	0.113	0.37	0.089

*SRT = Solids Retention Time
**FS = Fixed Solids

FIGURE A-2. FLOW DIAGRAM FOR HIGH-RISE, UNDERCAGE DRYING DESIGN ANALYSIS COMPUTER PROGRAM


Start
Specify Design Values for Area Factor and Vapor Pressure Differential
Specify Design Values for Bird Density and Initial Manurial Surface Moisture Content
Read a Value for Moisture Production per Bird-Day
Calculate Moisture Loading Factor
Calculate Design Drying Air Velocity
Print Moisture Production per Bird-Day, Moisture Loading Factor, and Design Drying Air Velocity
2
1


2
1
No
Have All Values for Moisture Production per Bird-Day Been Read?
Yes
Specify Design Values for Initial Manurial Surface Moisture Content and Moisture Production per Bird-Day
Read a Value for Bird Density
Calculate Moisture Loading Factor
Calculate Design Drying Air Velocity
Print Bird Density, Moisture Loading Factor, and Design Drying Air Velocity
No
Have All Values for Bird Density Been Read?
Yes
3


3
Specify Design Values for Moisture Production per Bird-Day and Bird-Density
Read a Value for Design Manurial Surface Moisture Content
Calculate Moisture Loading Factor
Calculate Design Drying Air Velocity
Print Manurial Surface Moisture Content and Design Drying Air Velocity
Have all Values for Manurial Surface Moisture Content Been Read?
No
Yes
Stop

```
C      HIGH-RISE, UNDERCAGE DRYING DESIGN ANALYSIS
C      AF = AREA FACTOR. DIMENSIONLESS
C      VPD = VAPOR PRESSURE DIFFERENTIAL. PASCALS
C      MSFDB = MANURIAL SURFACE MOISTURE CONTENT. PERCENT DRY BASIS
C      BD = BIRD DENSITY, BIRDS/M2
C      MP = MOISTURE PRODUCTION, GMS H2O/BIRD-DAY
C      MLF = MOISTURE LOADING FACTOR. KG H2O/M2-DAY
C      AV = DESIGN DRYING AIR VELOCITY, M/SEC
       REAL AF,VPD,MSFDB,BD,MP,MLF,AV,W,X,Y,Z
       READ,AF,VPD
C      SIMULATION OF THE EFFECT OF VARIATION OF MOISTURE PRODUCTION ON
C      DESIGN DRYING AIR VELOCITY
       WRITE(6,1)
     1 FORMAT('0',5X,'SIMULATION OF VARIATION OF MOISTURE PRODUCTION ON D
      *ESIGN DRYING AIR VELOCITY')
       READ,MSFDB,BD
       WRITE(6,2)
     2 FORMAT('0',5X,'AREA FACTOR = 1.0'/5X,'VAPOR PRESSURE DIFFERENTIAL
      *= 325 PASCALS'/5X,'MANURIAL SURFACE MOISTURE CONTENT = 235 %, DRY
      *BASIS'/5X,'BIRD DENSITY = 29.1 BIRDS/M2')
       WRITE(6,6)
     6 FORMAT('0',5X,'MOISTURE PRODUCTION,',5X,'MOISTURE LOADING FACTOR,'
      *,5X,'DESIGN DRYING AIR'/5X,'GMS H2O/BIRD-DAY',9X,'KG H2O/M2-DAY',1
      *6X,'VELOCITY, M/SEC')
     7 READ,MP
       IF(MP.EQ.0) GO TO 10
       MLF = (MP/1000)*(BD)
       AV=EXP((ALOG(MSFDB/2271))/(-0.494)-ALOG(AF/MLF)-ALOG(VPD))
       WRITE(6,8) MP,MLF,AV
     8 FORMAT(' ',12X,F5.1,23X,F4.2,22X,F4.2)
       GO TO 7
C      SIMULATION OF THE EFFECT OF VARIATION OF BIRD DENSITY ON DESIGN
```

Figure A-3. High-rise, undercage drying design analysis - source listing.

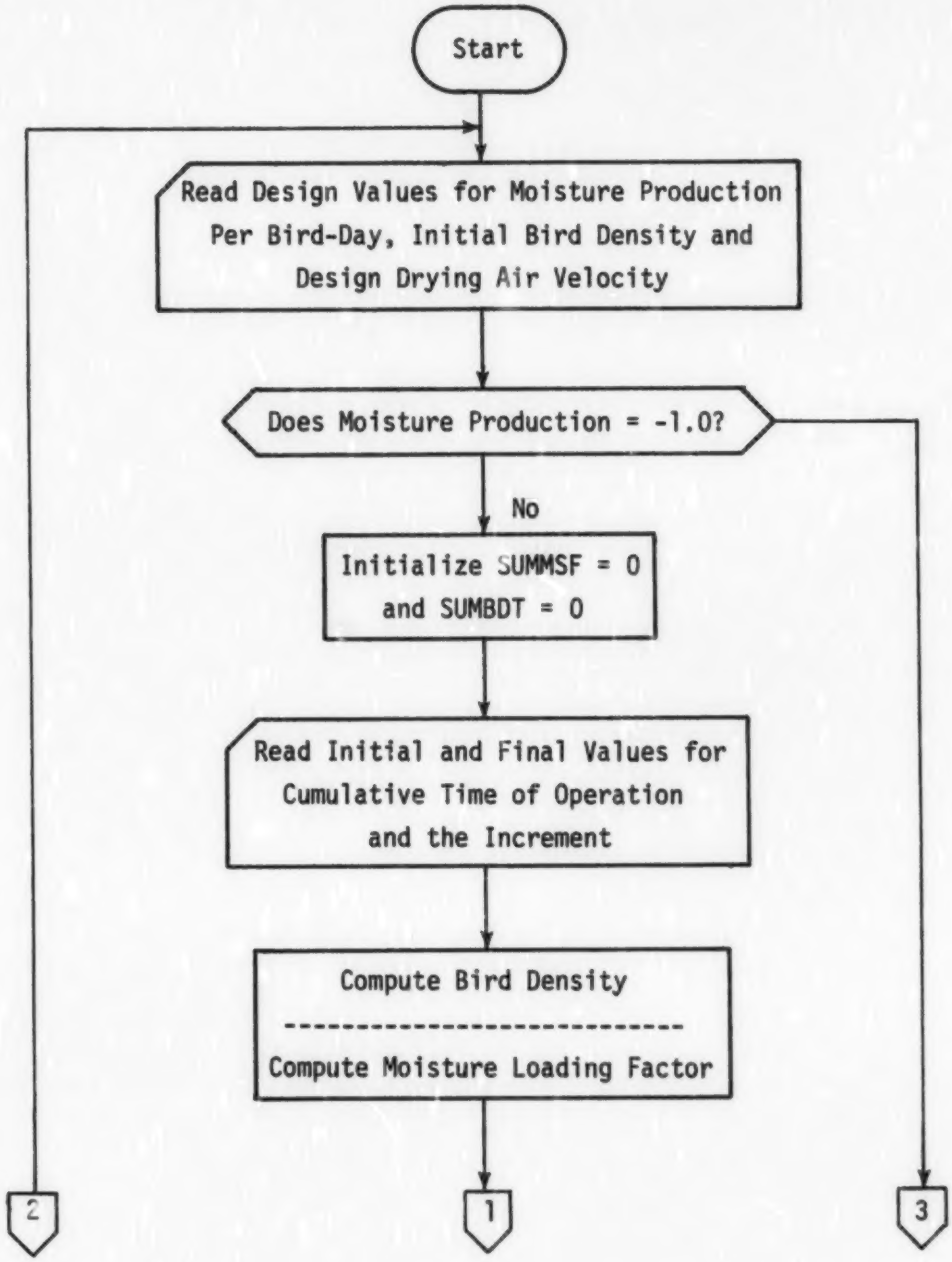
```
C     DRYING AIR VELOCITY
   10 WRITE(6,11)
   11 FORMAT('0',5X,'SIMULATION OF THE EFFECT OF VARIATION OF BIRD DENSI
     *TY ON DESIGN DRYING AIR VELOCITY')
      READ,MSFDB,MP
      WRITE(6,12)
   12 FORMAT('0',5X,'AREA FACTOR = 1.0'/5X,'VAPOR PRESSURE DIFFERENTIAL
     *= 325 PASCALS'/5X,'MANURIAL SURFACE MOISTURE CONTENT = 235%, DRY B
     *ASIS'/5X,'MOISTURE PRODUCTION = 90.6 GMS H2O/BIRD-DAY')
      WRITE(6,14)
   14 FORMAT('0',5X,'BIRD DENSITY,',12X,'MOISTURE LOADING FACTOR,',5X,'D
     *ESIGN DRYING AIR'/5X,'BIRDS/M2',17X,'KG H2O/M2-DAY',16X,'VELOCITY,
     *M/SEC')
   16 READ,BD
      IF(BD.EQ.0) GO TO 20
      MLF = (MP/1000)*(BD)
      AV=EXP((ALOG(MSFDB/2271))/(-0.494)-ALOG(AF/MLF)-ALOG(VPD))
      WRITE(6,18) BD,MLF,AV
   18 FORMAT(' ',9X,F4.1,27X,F4.2,22X,F4.2)
      GO TO 16
C     SIMULATION OF THE EFFECT OF VARIATION OF DESIGN MANURIAL SURFACE
C     MOISTURE CONTENT ON DESIGN DRYING AIR VELOCITY
   20 WRITE(6,21)
   21 FORMAT('0',5X,'SIMULATION OF THE EFFECT OF VARIATION OF DESIGN MAN
     *URIAL SURFACE MOISTURE CONTENT ON DESIGN DRYING AIR VELOCITY')
      READ,MP,BD
      WRITE(6,22)
   22 FORMAT('0',5X,'AREA FACTOR = 1.0'/5X,'VAPOR PRESSURE DIFFERENTIAL
     *= 325 PASCALS'/5X,'MOISTURE PRODUCTION = 90.6 GMS H2O/BIRD-DAY'/5X
     *,'BIRD DENSITY = 29.1 BIRDS/M2')
      WRITE(6,24)
```

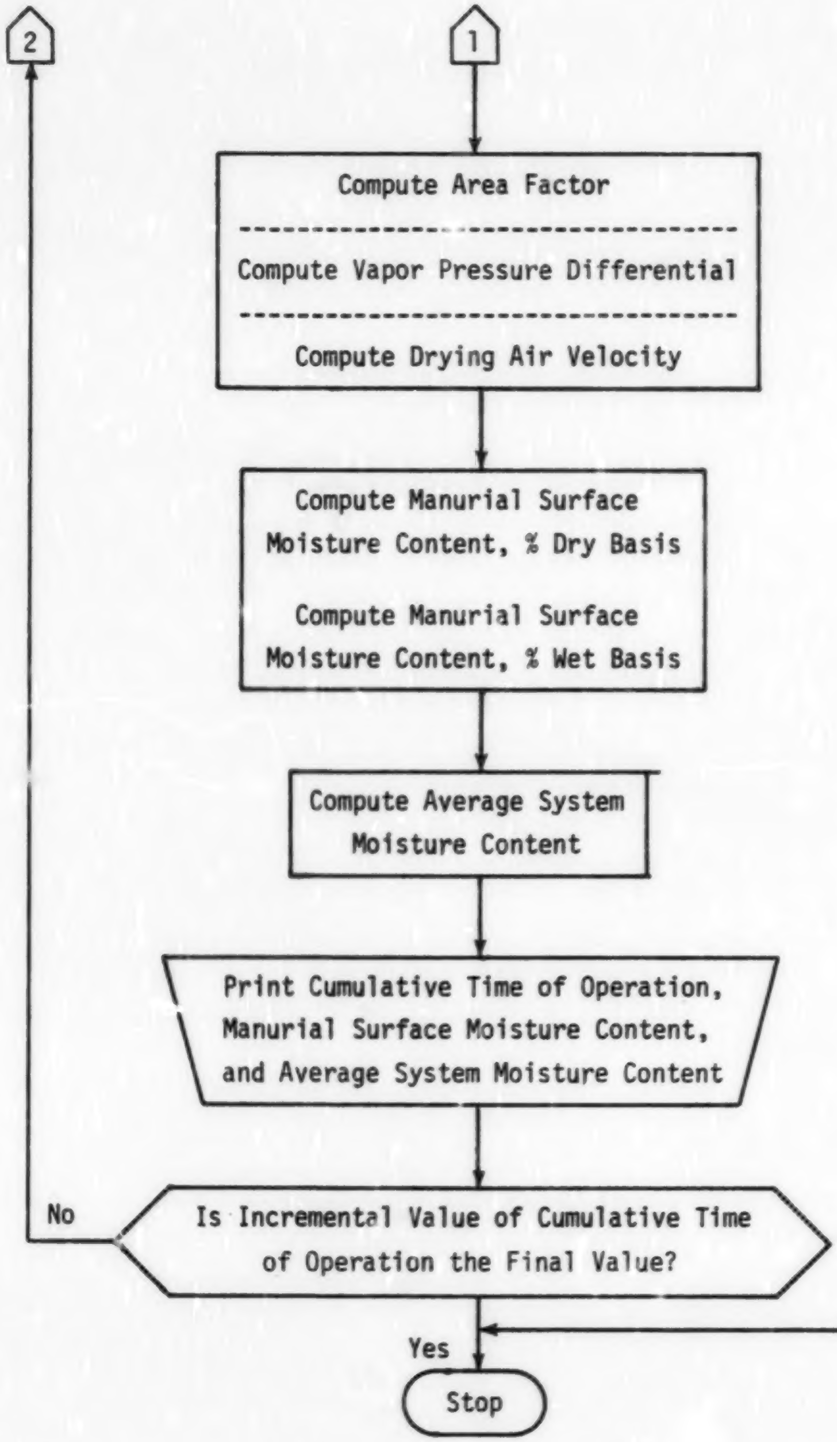
Figure A-3. (Continued)

```
24 FORMAT('0',5X,'MANURIAL SURFACE MOISTURE'.5X.'DESIGN DRYING AIR'/5
  *X,'CONTENT, % DRY BASIS'.10X,'VELOCITY, M/SEC')
26 READ,MSFDB
   IF(MSFDB.EQ.0) GO TO 99
   MLF = (MP/1000)*(BD)
   AV=EXP((ALOG(MSFDB/2271))/(-0.494)-ALOG(AF/MLF)-ALOG(VPD))
   WRITE(6,28) MSFDB,AV
28 FORMAT(' '.15X.F5.1.22X,F4.2)
   GO TO 26
99 STOP
   END
```

Figure A-3. (Continued)

FIGURE A-4. FLOW DIAGRAM FOR HIGH-RISE, UNDERCAGE DRYING: SIMULATION OF SYSTEM PERFORMANCE


Start
Read Design Values for Moisture Production Per Bird-Day, Initial Bird Density and Design Drying Air Velocity
Does Moisture Production = -1.0?
No
Initialize SUMMSF = 0 and SUMBDT = 0
Read Initial and Final Values for Cumulative Time of Operation and the Increment
Compute Bird Density
Compute Moisture Loading Factor
2
1
3


2
1
3
Compute Area Factor
Compute Vapor Pressure Differential
Compute Drying Air Velocity
Compute Manurial Surface Moisture Content, % Dry Basis
Compute Manurial Surface Moisture Content, % Wet Basis
Compute Average System Moisture Content
Print Cumulative Time of Operation, Manurial Surface Moisture Content, and Average System Moisture Content
No
Is Incremental Value of Cumulative Time of Operation the Final Value?
Yes
Stop

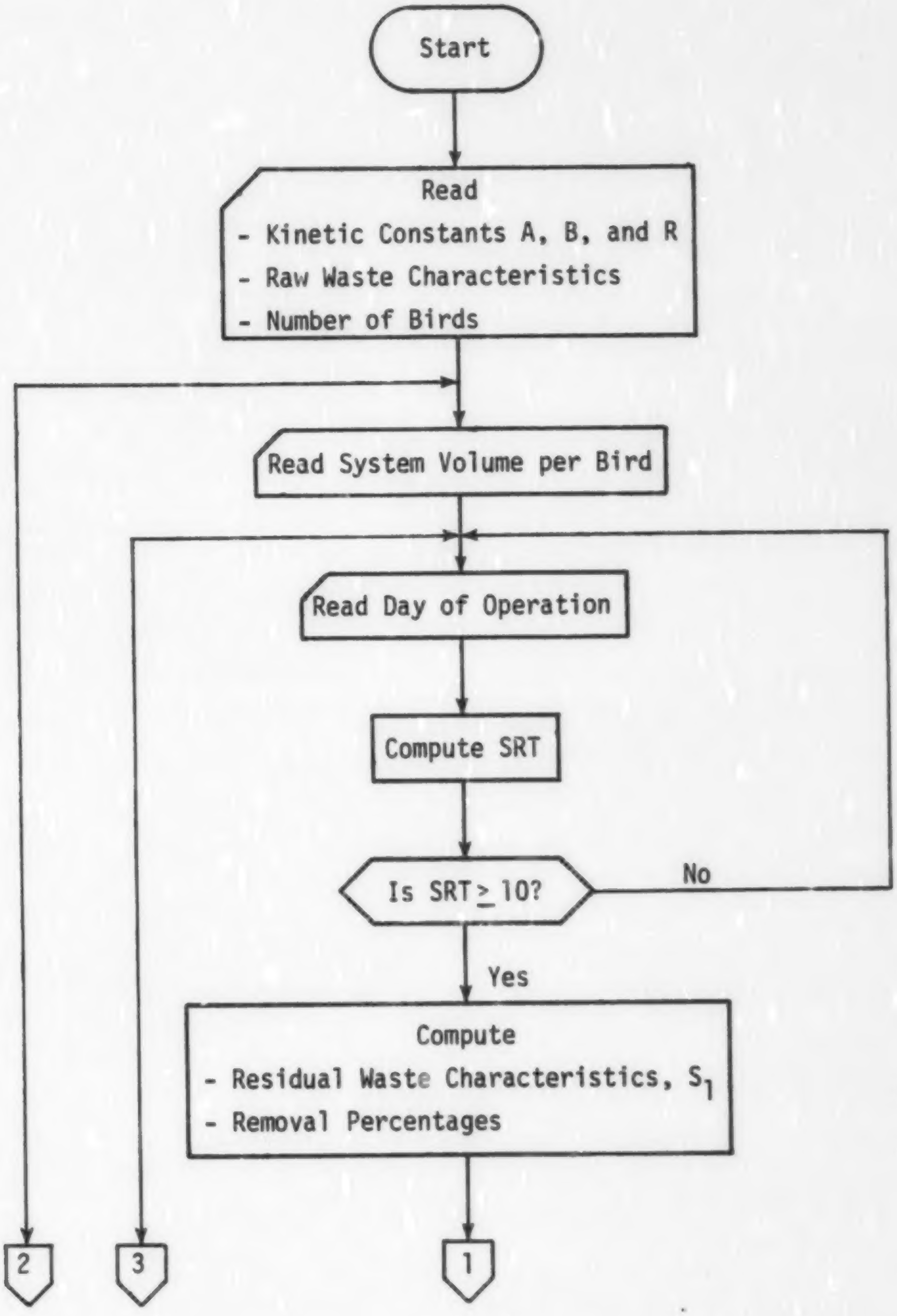
```
C     HIGH-RISE, UNDERCAGE DRYING--SIMULATION OF SYSTEM PERFORMANCE
      REAL MP,AV,BDI,BDT,MLFT,AFT,VPDT,XT,MSFDBT,MSFWBT,WAVMSF,SUMMSF,SU
     *MBDT,AVSYMC,AVI,AVT
      INTEGER T
C     T=CUMULATIVE TIME OF OPERATION, DAYS
C     MP=MOISTURE PRODUCTION, GMS H2O/BIRD-DAY---A CONSTANT
C     BDI=INITIAL BIRD DENSITY, BIRDS/M2
C     BDT=BIRD DENSITY AT T
C     MLF=MOISTURE LOADING FACTOR, KG H2O/M2-DAY
C     MLFT=MLF AT T
C     AF=AREA FACTOR, DIMENSIONLESS
C     AFT=AF AT T
C     AV=AVERAGE DRYING AIR VELOCITY, M/SEC
C     AVI=AVERAGE INITIAL DRYING AIR VELOCITY, M/SEC
C     AVT=AV AT T
C     VPD=VAPOR PRESSURE DIFFERENTIAL, PASCALS
C     VPDI=VPD AT T
C     X=AN INTERMEDIATE VALUE
C     XT=X AT T
   10 READ,MP,AVI,BDI
      IF(MP.EQ.-1.0) GO TO 99
      WRITE(6,11) MP
   11 FORMAT('1','MOISTURE PRODUCTION,GMS H2O/BIRD-DAY=',5X,F7.3)
      WRITE(6,12) AVI
   12 FORMAT(' ','AVERAGE INITIAL DRYING AIR VELOCITY,M/SEC=',1X,F6.3)
      WRITE(6,13) BDI
   13 FORMAT(' ','INITIAL BIRD DENSITY,BIRDS/M2=',13X,F6.3)
      SUMMSF=0
      SUMBDT=0
   18 DO 34 T=1,361,30
      BDT=(-0.01*T)+BDI
      MLFT=(MP/1000)*BDI
```

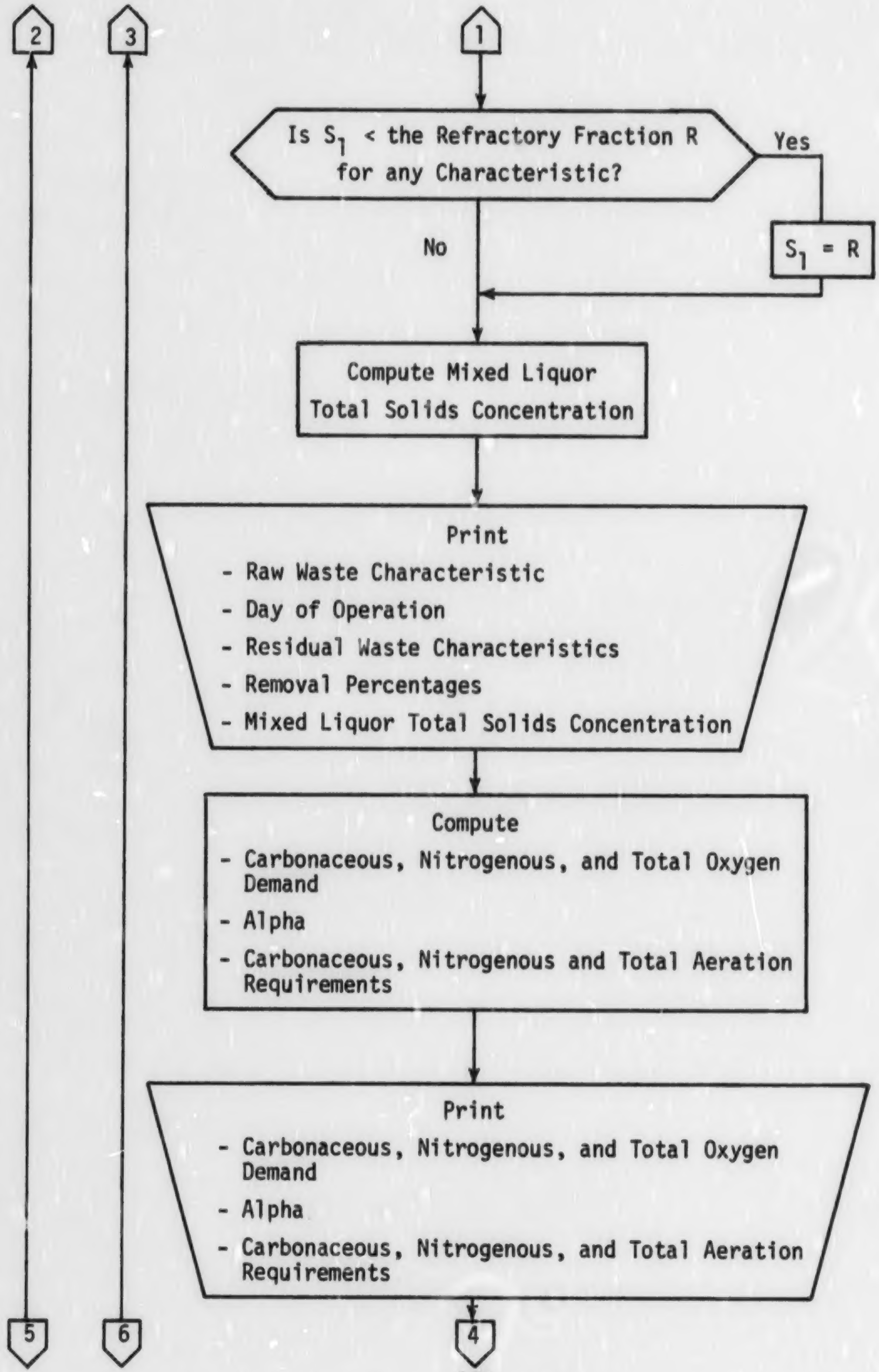
Figure A-5. High-rise, undercage drying: simulation of system performance - source listing.

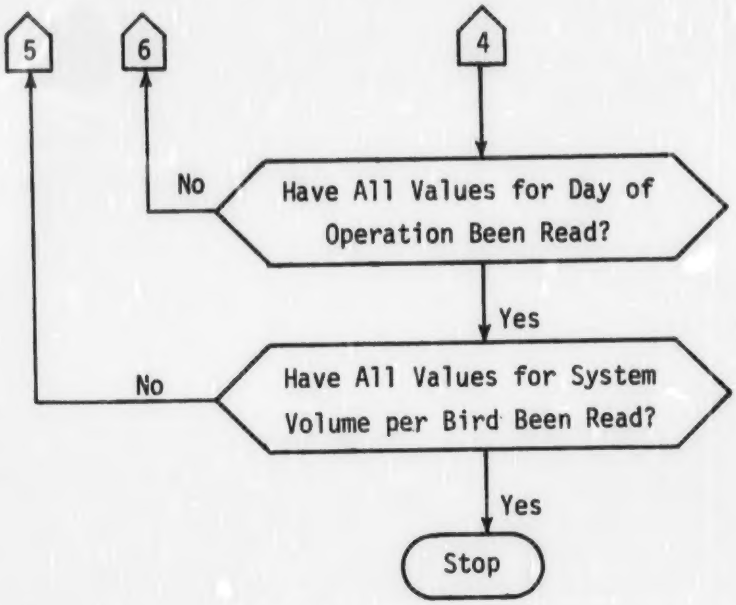
```
      AFT=1.0+(0.0016*T)
      AVT=AVI
      IF(T.LT.200) GO TO 20
      IF(T.GE.200) GO TO 22
   20 VPDT=(2.3*T)+238
      GO TO 24
   22 VPDT=(14.2*T)-2148
   24 XT=(AFT/MLFT)*AVT*VPDT
      MSFDBT=2271*(XT**(-0.494))
      MSFWBT=100*MSFDBT/(100+MSFDBT)
      WAVMSF=MSFWBT*BDT
      SUMMSF=SUMMSF+WAVMSF
      SUMBDT=SUMBDT+BDT
      AVSYMC=SUMMSF/SUMBDT
      WRITE(6,30) T
   30 FORMAT('0'.5X.'CUMULATIVE TIME OF OPERATION T. DAYS =',I14)
      WRITE(6,32) MSFWBT
   32 FORMAT(' ',5X,'MANURIAL SURFACE MOISTURE CONTENT AT T, % W.B.=',F5
     *.1)
      WRITE(6,33) AVSYMC
   33 FORMAT(' ',5X,'AVERAGE SYSTEM MOISTURE CONTENT AT T, % W.B.=',F8.1
     *)
   34 CONTINUE
      GO TO 10
   99 STOP
      END
```

Figure A-5. (Continued)

FIGURE A-6. FLOW DIAGRAM FOR BATCH MODE AERATION SYSTEM PROCESS DESIGN


Start
Read
- Kinetic Constants A, B, and R
- Raw Waste Characteristics
- Number of Birds
Read System Volume per Bird
Read Day of Operation
Compute SRT
Is SRT ≥ 10?
No
Yes
Compute
- Residual Waste Characteristics, S_1
- Removal Percentages
2
3
1


2
3
1
Is S_1 < the Refractory Fraction R for any Characteristic?
Yes
S_1 = R
No
Compute Mixed Liquor Total Solids Concentration
Print
- Raw Waste Characteristic
- Day of Operation
- Residual Waste Characteristics
- Removal Percentages
- Mixed Liquor Total Solids Concentration
Compute
- Carbonaceous, Nitrogenous, and Total Oxygen Demand
- Alpha
- Carbonaceous, Nitrogenous and Total Aeration Requirements
Print
- Carbonaceous, Nitrogenous, and Total Oxygen Demand
- Alpha
- Carbonaceous, Nitrogenous, and Total Aeration Requirements
5
6
4


5
6
4
No
Have All Values for Day of Operation Been Read?
Yes
No
Have All Values for System Volume per Bird Been Read?
Yes
Stop

```
C     LINEAR REGRESSION REMOVAL RELATIONSHIPS-BATCH MODEL
      REAL ATS,AVS,ACOD,AON,BTS,BVS,BCOD,BON,RTS,RVS,RCOD,RON,TSSO,VSSO,
     *CODSO,ONSO,NBIRDS,VOLBD,DAYOPR,MLTS,CARBOD,NOD,TOD,ALPHA,CO2REQ,NO
     *2REQ,TO2REQ,TSPC,VSPC,CODPC,ONPC
C     TS = TOTAL SOLIDS
C     VS = VOLATILE SOLIDS
C     COD = CHEMICAL OXYGEN DEMAND
C     ON = ORGANIC NITROGEN
C     SO = RAW WASTE QUANTITY, GM/BIRD-DAY
C     S1 = RESIDUAL WASTE FRACTION, GM/BIRD-DAY
C     SOR = REFRACTORY WASTE FRACTION, GM/BIRD-DAY
C     PC = PERCENT
C     SRT = SOLIDS RETENTION TIME, DAYS
C     MLTS = MIXED LIQUOR TOTAL SOLIDS CONCENTRATION, GM/L
C     NBIRDS = NUMBER OF BIRDS
C     CARBOD = CARBONACEOUS OXYGEN DEMAND, GM O2/HR
C     NOD = NITROGENOUS OXYGEN DEMAND, GM O2/HR
C     TOD = TOTAL OXYGEN DEMAND, GM O2/HR
C     CO2REQ = CARBONACEOUS OXYGENATION REQUIREMENTS, GM O2/HR
C     NO2REQ = NITROGENOUS OXYGENATION REQUIREMENTS, GM O2/HR
C     TO2REQ = TOTAL OXYGENATION REQUIREMENTS, GM O2/HR
C     VOLBD = VOLUME PER BIRD, L/BIRD
C     DAYOPR = CUMULATIVE TIME OF OPERATION, DAYS
C     READ KINETIC CONSTANTS
    1 READ,ATS,AVS,ACOD,AON,BTS,BVS,BCOD,BON,RTS,RVS,RCOD,RON
      WRITE(6,2)
    2 FORMAT('-',24X,'FIXED CONSTANT VALUES')
      WRITE(6,3)
    3 FORMAT('0','PARAMETER',12X,'A VALUES',2X,'B VALUES',2X,'R VALUES')
      WRITE(6,4) ATS,BTS,RTS
    4 FORMAT('0','TOTAL SOLIDS',4X,F10.3,F11.3,F9.3)
      WRITE(6,5) AVS,BVS,RVS
```

Figure A-7. Batch aeration system design program - source listing.

```
    5 FORMAT(' ','VOLATILE SOLIDS',1X,F10.3,F11.3,F9.3)
      WRITE(6,6) ACOD,BCOD,RCOD
    6 FORMAT(' ','COD',13X,F10.3,F11.3,F9.3)
      WRITE(6,7) AON,BON,RON
    7 FORMAT(' ','ORGANIC NITROGEN',F10.3,F11.3,F9.3)
C     READ RAW WASTE CHARACTERISTICS EXPRESSED AS GMS/BIRD-DAY
   10 READ,TSS0,VSS0,CODS0,ONS0
      WRITE(6,11)
   11 FORMAT('-','RAW WASTE CHARACTERISTICS, GMS/BIRD-DAY')
      WRITE(6,12) TSS0
   12 FORMAT('0','TOTAL SOLIDS',7X,F6.3)
      WRITE(6,13) VSS0
   13 FORMAT(' ','VOLATILE SOLIDS',4X,F6.3)
      WRITE(6,14) CODS0
   14 FORMAT(' ','COD',16X,F6.3)
      WRITE(6,15) ONS0
   15 FORMAT(' ','ORGANIC NITROGEN',3X,F6.3)
C     READ NUMBER OF BIRDS
      READ,NBIRDS
      WRITE(6,16) NBIRDS
   16 FORMAT('0','NUMBER OF BIRDS',5X,F10.0)
C     READ SYSTEM VOLUME/BIRD, LITERS/BIRD
   20 READ,VOLBD
      IF(VOLBD.EQ.0) GO TO 99
      WRITE(6,22) VOLBD
   22 FORMAT('-','SYSTEM VOLUME/BIRD, LITERS/BIRD',F10.1)
   24 READ,DAYOPR
      IF(DAYOPR)20,24,26
   26 SRT=DAYOPR/2
      IF(SRT.GT.9.99) GO TO 30
      GO TO 24
   30 CALL CALC (ATS,BTS,TSS0,TSS1,RTS,TSPC,SRT,TSSOR,TSPCB)
```

Figure A-7. (Continued)

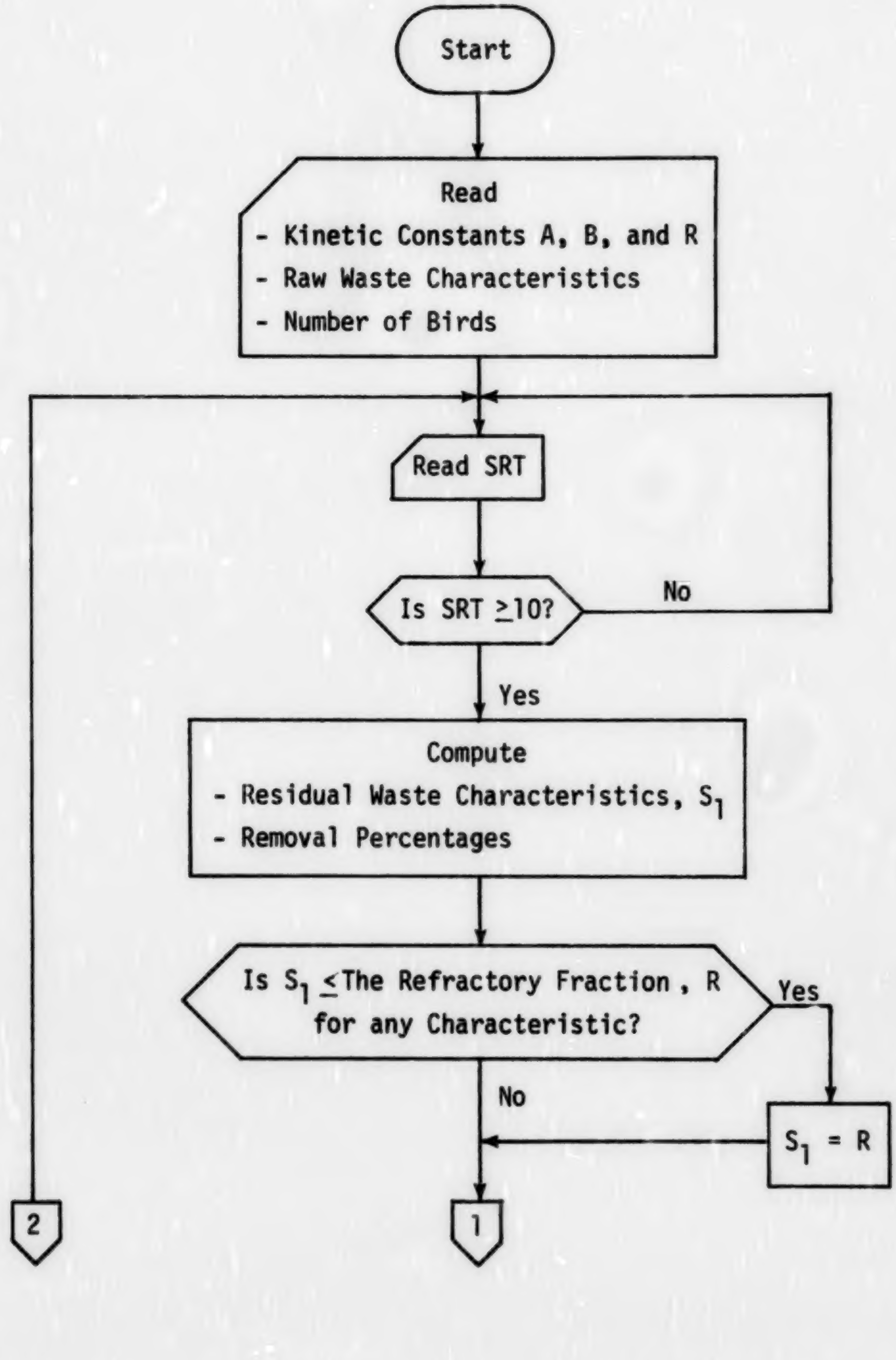
```
      CALL CALC (AVS,BVS,VSS0,VSS1,RVS,VSPC,SRT,VSS0R,VSPCB)
      CALL CALC (ACOD,BCOD,CODS0,CODS1,RCOD,CODPC,SRT,CODS0R,CODPSC)
      CALL CALC (AON,BON,ONS0,ONS1,RON,ONPC,SRT,ONS0R,ONPCB)
      WRITE(6,32)
   32 FORMAT('-',5X,'DAY',5X,'-----TOTAL     SOLIDS------',4X,'----VOLATI
     *LE    SOLIDS----',4X,'-----------COD------------',4X,'----ORGANIC
     *   NITROGEN----')
      WRITE(6,33)
   33 FORMAT(' ',6X,'OF')
      WRITE(6,34)
   34 FORMAT(' ',2X,'OPERATION',4(5X,'S0',8X,'S1',5X,'% REMOVAL'))
      WRITE(6,35)DAYOPR,TSS0,TSS1,TSPC,VSS0,VSS1,VSPC,CODS0,CODS1,CODPC,
     *ONS0,ONS1,ONPC
   35 FORMAT(/13F10.3)
C     CALCULATE MIXED LIGUOR TOTAL SOLIDS CONCENTRATION
   40 MLTS=(TSS0*DAYOPR*(1-TSPC/100))/VOLBD
      WRITE(6,41)MLTS
   41 FORMAT('0','MIXED LIGUOR TOTAL SOLIDS CONCENTRATION,GMS/LITER',5X,
     *F10.1)
C     CALCULATE MICROBIAL OXYGEN DEMAND,GMS O2/HR
   42 CARBOD=(CODS0*NBIRDS*CODPC/100)/24
      NOD=((ONS0*NBIRDS*ONPC/100)/24)*4.57
      TOD=COD+NOD
      WRITE(6,44)
   44 FORMAT('0','MICROBIAL OXYGEN DEMAND AND AERATION REQUIREMENTS')
      WRITE(6,45) CARBOD
   45 FORMAT('0','CARBONACEOUS OXYGEN DEMAND, GMS O2/HR',F10.1)
      WRITE(6,46) NOD
   46 FORMAT(' ','NITROGENOUS OXYGEN DEMAND, GMS O2/HR',1X,F10.1)
      WRITE(6,47) TOD
   47 FORMAT(' ','TOTAL OXYGEN DEMAND, GMS O2/HR',8X,F10.1)
C     CALCULATE AERATION REQUIREMENTS
```

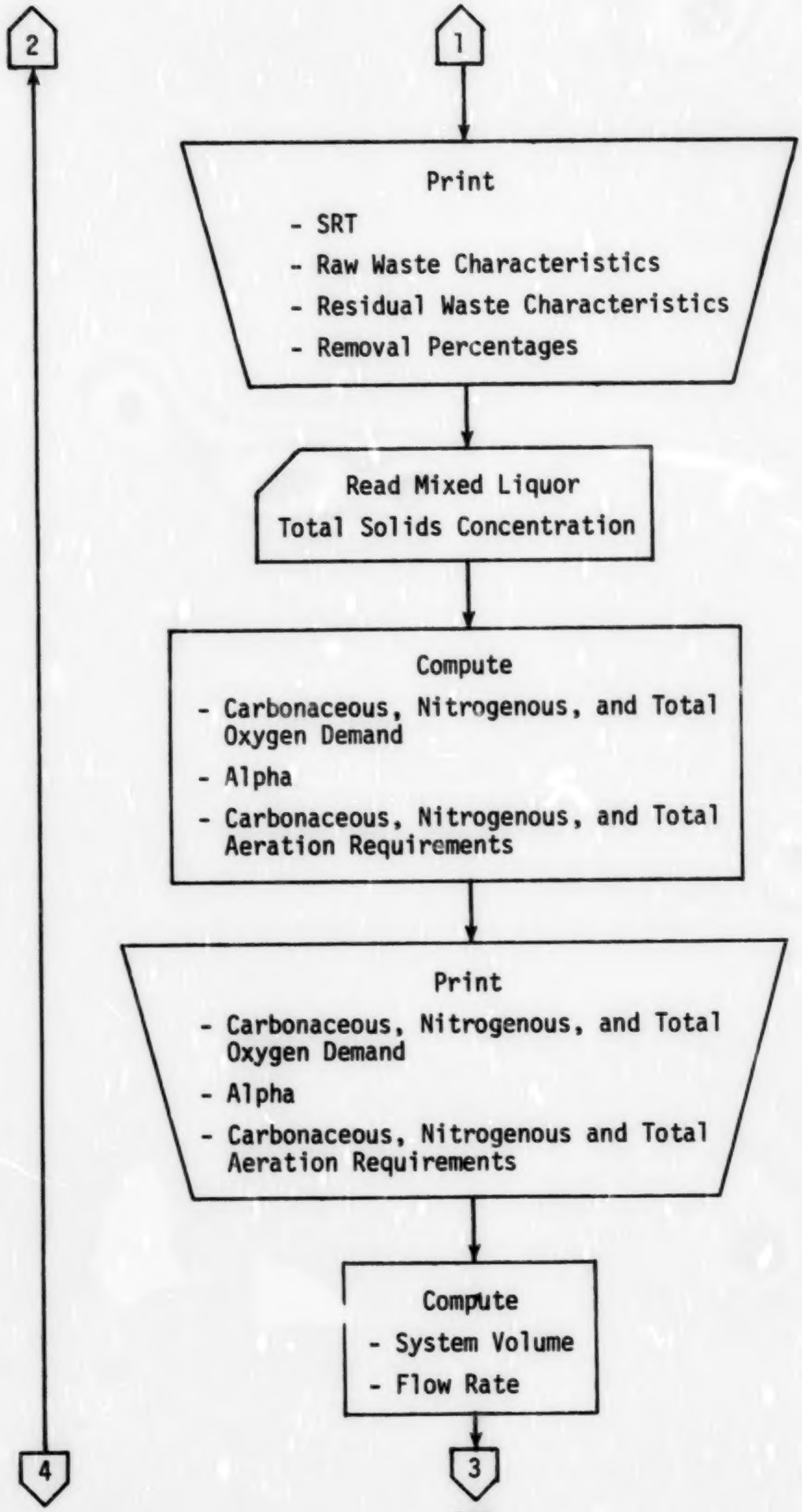
Figure A-7. (Continued)

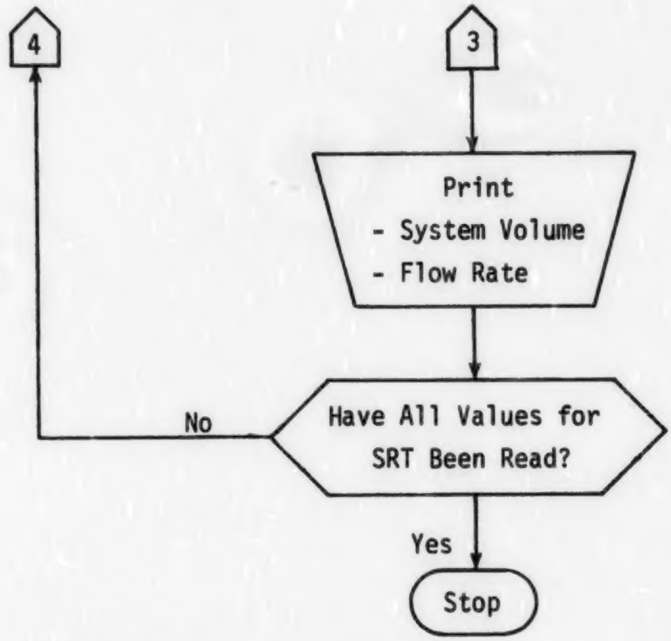
```
      IF(MLTS.LE.20) ALPHA=1
      IF(MLTS.GT.20.AND.MLTS.LT.55) ALPHA=(1.36-(.017*MLTS))
      IF(MLTS.GE.55) ALPHA=0.4
      WRITE(6,50) ALPHA
   50 FORMAT(' ','ALPHA',32X,F10.2)
      CO2REQ=CARBOD/ALPHA
      NO2REQ=NOD/ALPHA
      TO2REQ=TOD/ALPHA
      WRITE(6,51) CO2REQ
   51 FORMAT('0','CARBONACEOUS OXYGEN REQUIREMENTS, GMS O2/HR',3X,F10.1)
      WRITE(6,52) NO2REQ
   52 FORMAT(' ','NITROGENOUS OXYGEN REQUIREMENTS. GMS O2/HR',4X,F10.1)
      WRITE(6,53) TO2REQ
   53 FORMAT(' ','TOTAL OXYGEN REQUIREMENTS, GMS O2/HR',10X,F10.1)
      GO TO 24
   99 STOP
      END


C     SUBROUTINE TO CALCULATE % REMOVAL AND EFFLUENT CHARACTERISTICS
      SUBROUTINE CALC (A,B,S0,S1,R,PC,SRT,SOR,PCB)
      REAL A,B,S0,S1,R,PC,SRT,SOR,PCB
      PC=A*SRT+B
      S1=S0*(1-PC/100)
      SOR=S0*R
      IF(S1.LT.SOR) S1=SOR
      PCB=(100-(R*100))
      IF(PC.GT.PCB) PC=PCB
      RETURN
      END
```

Figure A-7. (Continued)

FIGURE A-8. FLOW DIAGRAM FOR CONTINUOUS FLOW MODE AERATION SYSTEM PROCESS DESIGN


Start
Read
- Kinetic Constants A, B, and R
- Raw Waste Characteristics
- Number of Birds
Read SRT
Is SRT ≥10?
No
Yes
Compute
- Residual Waste Characteristics, S_1
- Removal Percentages
Is $S_1 \leq$ The Refractory Fraction , R for any Characteristic?
Yes
No
$S_1 = R$
2
1


2
1
Print
- SRT
- Raw Waste Characteristics
- Residual Waste Characteristics
- Removal Percentages
Read Mixed Liquor Total Solids Concentration
Compute
- Carbonaceous, Nitrogenous, and Total Oxygen Demand
- Alpha
- Carbonaceous, Nitrogenous, and Total Aeration Requirements
Print
- Carbonaceous, Nitrogenous, and Total Oxygen Demand
- Alpha
- Carbonaceous, Nitrogenous and Total Aeration Requirements
Compute
- System Volume
- Flow Rate
4
3


4
3
Print
- System Volume
- Flow Rate
Have All Values for SRT Been Read?
No
Yes
Stop

```
C     LINEAR REGRESSION REMOVAL RELATIONSHIPS-CONTINUOUS FLOW MODEL
      REAL ATS,AVS,ACOD,AON,BTS,BVS,BCOD,BON,RTS,RVS,RCOD,RON,TSS0,VSS0,
     *CODS0,ONS0,TSS1,VSS1,CODS1,ONS1,TSPC,VSPC,CODPC,ONPC,SRT,TSS0R,VSS
     *0R,CODS0R,ONS0R,TSPCB,VSPCB,CODPCB,ONPCB,NBIBDS,MLTS,CARBOD,NOD,TO
     *D,ALPHA,SVOL,CO2REQ,NO2REQ,TO2REQ,FLORTE
C     TS = TOTAL SOLIDS
C     VS = VOLATILE SOLIDS
C     COD = CHEMICAL OXYGEN DEMAND
C     ON = ORGANIC NITROGEN
C     SO = RAW WASTE QUANTITY, GM/BIRD-DAY
C     S1 = RESIDUAL WASTE FRACTION, GM/BIRD-DAY
C     SOR = REFRACTORY WASTE FRACTION, GM/BIRD-DAY
C     PC = PERCENT
C     SRT = SOLIDS RETENTION TIME, DAYS
C     MLTS = MIXED LIQUOR TOTAL SOLIDS CONCENTRATION, GM/L
C     NBIRDS = NUMBER OF BIRDS
C     CARBOD = CARBONACEOUS OXYGEN DEMAND, GM O2/HR
C     NOD = NITROGENOUS OXYGEN DEMAND, GM O2/HR
C     TOD = TOTAL OXYGEN DEMAND, GM O2/HR
C     CO2REQ = CARBONACEOUS OXYGENATION REQUIREMENTS, GM O2/HR
C     NO2REQ = NITROGENOUS OXYGENATION REQUIREMENTS, GM O2/HR
C     TO2REQ = TOTAL OXYGENATION REQUIREMENTS, GM O2/HR
C     SVOL = SYSTEM VOLUME, L
C     FLORTE = FLOW RATE, L/DAY
C     INTRODUCTION OF CONSTANTS
    1 READ,ATS,AVS,ACOD,AON,BTS,BVS,BCOD,BON,RTS,RVS,RCOD,RON
      WRITE(6,2)
    2 FORMAT('0',24X,'FIXED CONSTANT VALUES')
      WRITE(6,3)
    3 FORMAT('0','PARAMETER',12X,'A VALUES',2X,'B VALUES',2X,'R VALUES')
```

Figure A-9. Continuous flow aeration system design program - source listing.

```
      WRITE(6,4) ATS,BTS,RTS
    4 FORMAT('0','TOTAL SOLIDS',4X,F10.3,F11.3,F9.3)
      WRITE(6,5) AVS,BVS,RVS
    5 FORMAT(' ','VOLATILE SOLIDS',1X,F10.3,F11.3,F9.3)
      WRITE(6,6) ACOD,BCOD,RCOD
    6 FORMAT(' ','COD',13X,F10.3,F11.3,F9.3)
      WRITE(6,7) AON,BON,RON
    7 FORMAT(' ','ORGANIC NITROGEN',F10.3,F11.3,F9.3)
C     READ RAW WASTE CHARACTERISTICS EXPRESSED AS GMS / BIRD-DAY
   10 READ,TSS0,VSS0,CODS0,ONS0
      WRITE(6,11)
   11 FORMAT('-','RAW WASTE CHARACTERISTICS, GMS/BIRD-DAY')
      WRITE(6,12) TSS0
   12 FORMAT('0','TOTAL SOLIDS',7X,F6.3)
      WRITE(6,13) VSS0
   13 FORMAT(' ','VOLATILE SOLIDS'.4X.F6.3)
      WRITE(6,14) CODS0
   14 FORMAT(' ','COD',16X,F6.3)
      WRITE(6,15) ONS0
   15 FORMAT(' ','ORGANIC NITROGEN'.3X.F6.3)
      READ,NBIRDS
      WRITE(6,16) NBIRDS
   16 FORMAT('0','NUMBER OF BIRDS',20X,F10.3)
   20 READ,SRT
      IF(SRT.EQ.0) GO TO 99
      IF(SRT.GE.10) GO TO 30
   25 READ,SRT
      IF(SRT.NE.99) GO TO 25
      GO TO 20
   30 CALL CALC (ATS,BTS,TSS0,TSS1,RTS,TSPC,SRT,TSSOR,TSPCB)
      CALL CALC (AVS,BVS,VSS0,VSS1,RVS,VSPC,SRT,VSSOR,VSPCB)
      CALL CALC (ACOD,BCOD,CODS0,CODS1,RCOD,CODPC,SRT,CODSOR,CODPCB)
```

Figure A-9. (Continued)

```
      CALL CALC (ACN,BON,ONS0,ONS1,RON,CNFC,SRT,ONSOR,ONPCB)
      WRITE(6,40)
   40 FORMAT('-',5X,'SRT',5X,'-----TOTAL     SOLIDS------',4X,'----VOLATI
     *LE    SOLIDS----',4X,'-----------COD------------',4X,'----ORGANIC
     *   NITROGEN----')
      WRITE(6,41)
   41 FORMAT('0',9X,4(5X,'S0',8X,'S1',5X,'% REMOVAL'))
      WRITE(6,50)SRT,TSS0.TSS1.TSPC,VSS0,VSS1.VSPC,CODS0,CODS1.CODPC,ONS
     *0,ONS1.ONPC
   50 FORMAT(/13F10.3)
   60 READ,MLTS
      IF(MLTS.EQ.99) GO TO 20
C     CALCULATION OF OXYGEN DEMAND. GMS O2/HR
      CARBOD=(CODS0*NBIRDS*CODPC/100)/24
      NOD=((ONS0*NBIRDS*ONPC/100)/24)*4.57
      TOD=COD+NOD
C     CALCULATION OF OXYGEN REQUIREMENTS
      IF(MLTS.LE.20) ALPHA=1
      IF(MLTS.GT.20.AND.MLTS.LT.55) ALPHA=(1.36-(.017*MLTS))
      IF(MLTS.GE.55) ALPHA=0.4
C     OXYGENATION REQUIREMENTS. GMS O2/HR=O2REQ
      CO2REQ=CARBOD/ALPHA
      NO2REQ=NOD/ALPHA
      TO2REQ=TOD/ALPHA
C     CALCULATION OF SYSTEM VOLUME.LITERS
      SVOL=((NBIRDS*TSS0*(TSPC/100))*SRT)/MLTS
C     CALCULATION OF FLOWRATE TO MAINTAIN SPECIFIED
C     MLTS CONCENTRATION,LITERS/DAY
      FLORTE=(TSS1*NBIRDS)/MLTS
      WRITE(6,63) MLTS
   63 FORMAT('-','MIXED LIQUOR TOTAL SOLIDS CONC',5X,F10.3)
      WRITE(6,64) ALPHA
```

Figure A-9. (Continued)

```
      64 FORMAT(' ','ALPHA',30X,F10.2)
         WRITE(6,68)
      68 FORMAT('-','MICROBIAL OXYGEN DEMAND AND AERATION REQUIREMENTS')
         WRITE(6,70) CARBOD
      70 FORMAT('0','CARBONACEOUS OXYGEN DEMAND, GMS O2/HR'.F10.1)
         WRITE(6,71) NOD
      71 FORMAT(' ','NITROGENOUS OXYGEN DEMAND.GMS O2/HR',1X.F10.1)
         WRITE(6,72) TOD
      72 FORMAT(' ','TOTAL OXYGEN DEMAND.GMS O2/HR',8X,F10.1)
         WRITE(6,73) CO2REQ
      73 FORMAT('0'.'CARBONACEOUS OXYGEN REQUIREMENTS, GMS O2/HR',3X.F10.1)
         WRITE(6,74) NO2REQ
      74 FORMAT(' ','NITROGENOUS OXYGEN REQUIREMENTS, GMS O2/HR',4X,F10.1)
         WRITE(6,75) TO2REQ
      75 FORMAT(' ','TOTAL OXYGEN REQUIREMENT. GMS O2/HR',10X,F10.1)
         WRITE(6,76) SVOL
      76 FORMAT(' ','SYSTEM VOLUME,LITERS',8X,F10.1)
         WRITE(6,78) FLORTE
      78 FORMAT(' ','FLOWRATE,LITERS/DAY'.9X,F10.1)
         GO TO 60
      99 STOP
         END



C        SUBROUTINE TO CALCULATE % REMOVAL AND EFFLUENT CHARACTERISTICS
         SUBROUTINE CALC (A,B,S0,S1,R,PC,SRT,SOR,PCB)
         REAL A,B,S0,S1,R,PC,SRT,SOR.PCB
         PC=A*SRT+B
         S1=S0*(1-PC/100)
         SOR=S0*R
         IF(S1.LT.SOR) S1=SOR
         PCB=(100-(R*100))
         IF(PC.GT.PCB) PC=PCB
         RETURN
         END
```

Figure A-9. (Continued)

FIGURE A-10. COST OF NITROGEN CONSERVATION WITH AERATION SYSTEMS FOR POULTRY WASTES

Assumptions

A. Nitrogen excreted = 1.94 gm/bird-day

B. Maximum potential for nitrogen conservation = 39%

C. Cost of oxygen transfer = \$0.058/kg O_2

D. Nitrogenous oxygen demand = 255 gm O_2/1000 bird-hours at 69 percent organic nitrogen removal

E. Uncontrollable nitrogen loss with nitrification = 30 percent

Quantity of Potentially Conservable Nitrogen per 1000 Bird-days

$$\frac{1.94 \text{ gm N}}{\text{Bird-day}} \times 1000 \text{ birds} \times 0.39 = 757 \text{ gm N/1000 bird-day}$$

Aeration Cost to Meet the Nitrogenous Oxygen Demand

$$\frac{0.255 \text{ kg } O_2}{1000 \text{ Bird-hr}} \times \frac{24 \text{ hr}}{\text{Day}} \times \frac{\$0.058}{\text{kg } O_2} = \$0.355/1000 \text{ bird-days}$$

Cost per Unit Nitrogen Conserved

$$\frac{\$0.355/1000 \text{ bird-days}}{0.757 \text{ kgN/1000 bird-days}} = \$0.469/\text{kgN } (\$0.213/\text{lbN})$$